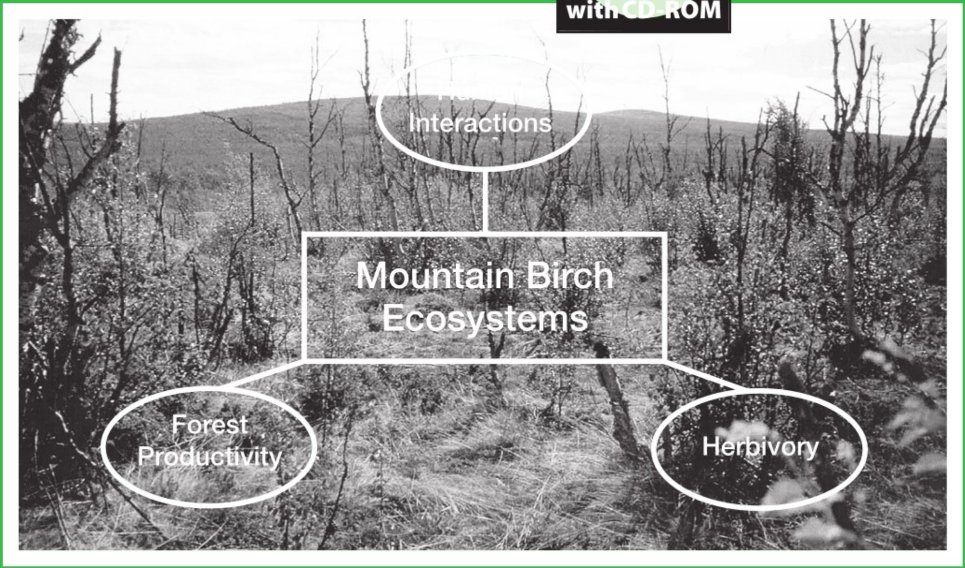
Ecological Studies 180

F. E. Wielgolaski (Ed.)

P. S. Karlsson S. Neuvonen
D. Thannheiser (Ed. Board)

Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

with CD-ROM



Springer

Ecological Studies, Vol. 180

Analysis and Synthesis

Ecological Studies

Volumes published since 2000 are listed at the end of this book.

F.E. Wielgolaski (Ed.)
P.S. Karlsson S. Neuvonen D. Thannheiser (Ed. Board)

Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

With 69 Figures, 21 Tables, and CD-ROM

Springer

Volume editor

Professor Dr. Frans E. Wielgolaski
University of Oslo
Department of Biology
P.O. Box 1045 Blindern
0316 Oslo, Norway

Editorial Board

Dr. P. Staffan Karlsson
Uppsala University
Department of Plant Ecology
Ecolutionary Biology Centre
Villavägen 14
75236 Uppsala, Sweden

Professor Dr. Seppo Neuvonen
University of Turku
Kevo Subarctic Research Institute
20014 Turku, Finland

Professor Dr. Dietbert Thannheiser
University of Hamburg
Department of Geography
Bundesstr. 55
20146 Hamburg, Germany

Cover illustration: Scheme after an idea of F.E. Wielgolaski. Background phto by H. Bylund (see Fig. 12.1)

ISSN 0070-8356
ISBN 3-540-22909-4 Springer-Verlag Berlin Heidelberg New York

Library of Congress Control Number: 2004113135

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permissions for use must always be obtained from Springer-Verlag. Violations are liable for prosecution under the German Copyright Law.

Springer is a part of Springer Science+Business Media
springeronline.com

© Springer-Verlag Berlin Heidelberg 2005
Printed in Germany

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Editor: Dr. Dieter Czeschlik, Heidelberg, Germany
Desk editor: Dr. Andrea Schlitzberger, Heidelberg, Germany
Cover design: *design & production* GmbH, Heidelberg, Germany
Typesetting and production: Friedmut Kröner, Heidelberg, Germany

31/3150 YK – 5 4 3 2 1 0 – Printed on acid free paper

Preface

In Fennoscandia and Iceland, large parts of particularly elevated areas are treeless. Below these areas there is often a belt of Nordic mountain birch trees, now often called *Betula pubescens* ssp. *czerepanovii.* In Fennoscandia, this plant is also common in a zone north of the coniferous trees and is found in small forests in the southwestern-most parts of Greenland and more locally in other parts of Europe.

Before the begin of the International Biological Programme (IBP) in the late 1960s and early 1970s, only minor fractions of these ecosystems had been studied. Therefore, alpine and subalpine systems were chosen as the main areas of study in this first, larger interdisciplinary and integrated project in natural science across national borders and, in this way, they made an important contribution to such research in the Nordic countries. In addition to an interdisciplinary steering committee in each country, a Nordic administration was also established for the so-called IBP "Tundra Biome" studies in the region (although permafrost is not common in most of the region). At the end of the IBP, many results from this research in alpine, subalpine and northern Fennoscandian mountain birch forests were published in two early volumes of the Ecological Studies Series (Wielgolaski 1975a, b).

As is common at the end of scientific projects, many questions were not really answered, and this was also the case after IBP. However, the project showed the good collaboration within the Nordic countries. Therefore, in the late 1970s, it was decided to establish a "Nordic Subalpine–Subarctic Ecology" network project (NSSE) across the national borders within the Nordic mountain birch ecosystem at a lower intensity level, as only very limited funding was available for this cooperation after the IBP. In Finland, after some years, this project was accepted as a Man and Biosphere (MAB) network, resulting in a better status of the project in that country than elsewhere. This made it also possible to obtain results from the joint Nordic mountain birch studies more than 20 years after the IBP published their findings in a volume in the UNESCO-MAB Series (Wielgolaski 2001).

Within the EU, international scientific projects, including several European member countries and associated EU countries, are recognized as important to increase the knowledge and cooperation in Europe. Particularly important are natural science projects that also relate to man and socio-economy. Therefore, the 3-year project "Human Interactions with the Mountain Birch Ecosystem: Implications for Sustainable Development" (HIBECO) was funded by the EU from the year 2000. Here, results from new mountain birch studies in the Nordic countries including Greenland are added to older ones concerning both the growth of the birch itself, and the use and limitations of these forests by animals and man, with the objective of finding the best sustainable management for mankind in this ecosystem. Furthermore, Scotland was included in this project because of the good knowledge from earlier projects there on the influence of grazing, e.g. by sheep in their mountain birch regions. The results of this EU project are summarized in this volume.

What has changed in the Nordic mountain birch ecosystem in a long- or short-term perspective? In the short term, a possible increment of the forests in elevation by global climate change may be included, either induced by man or not. In Iceland, large areas of the original birch forests were cleared by man. Later, strong sheep grazing prevented resprouting of the trees and caused heavy erosion (Aradottir and Arnalds 2001). A similar development has, to some extent, taken place in the birch zone of southern Greenland. In addition, in Fennoscandia, the mountain birch forests have been suppressed in subalpine districts due to sheep grazing. In later years, however, this sheep-grazing pressure was lower in those areas. This may be another reason for the recent increased elevation of the upper birch tree line in the region, in addition to climate change. In northern Fennoscandia, the birch forests are strongly influenced by reindeer grazing and trampling, as reported in several chapters.

Modern infrastructure is also very important for development in the Nordic mountain birch region. A denser road net makes a larger fraction of the birch forests accessible for firewood cutting. Similarly, increased tourism after road building may increase the tree cutting and reduce the birch forests. At the same time, in some districts, less forest is used for firewood, because many inhabitants, also from the mountain birch region, are going over to heating by electricity and oil. This shows how sustainable use of mountain birch depends on the political decisions taken in a district.

The main objectives of the various chapters in this volume are to give examples from different sites (see Fig. 1) in the Nordic countries (and Scotland) of the influence of climate change and human decisions on growth of birch and the understorey. It has been discussed how climate change through time may be of importance for the adaptation of the trees in various regions and how such changes may cause variations in attacks, e.g. by insects. Shifts in the grazing pressure, e.g. by sheep and reindeer, will be important for the

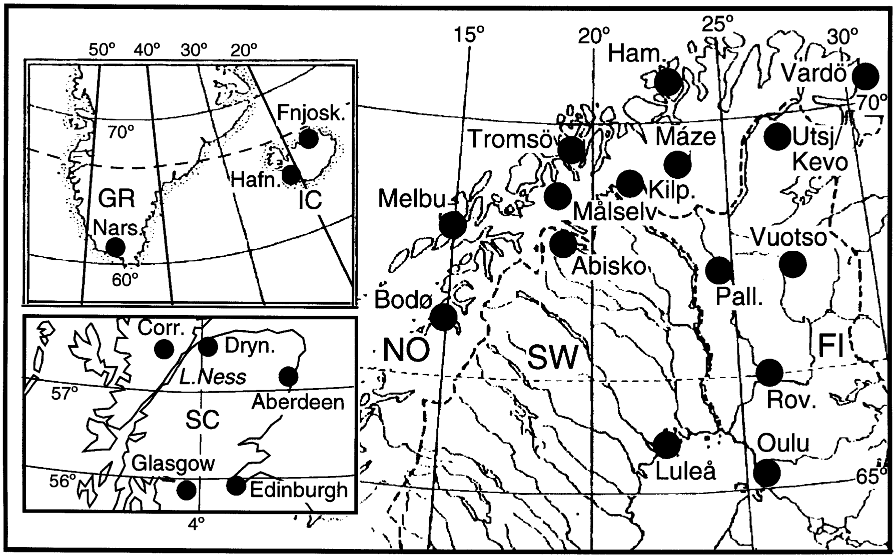


Fig. 1. Map of northern Fennoscandia (*FI* Finland, *SW* Sweden, *NO* Norway), Iceland (*IC*), southern Greenland (*GR*) and parts of Scotland (*SC*), showing sites used in connection with the HIBECO project and some towns in the regions (*Rov* Rovaniemi, *Pall* Pallasjärvi, *Kilp* Kilpisjärvi, *Utsj/Kevo* Utsjoki/Kevo, *Ham* Hammerfest, *Fnjosk* Fnjoskadalur, *Hafn* Hafnarskogur, *Nars* Narssarssuaq, *Dryn* Drynachan, *Corr* Corrimony). *Broken line* at 66°33′N denotes Arctic Circle. Provenance sites used in phenology studies are given in the Fig. 7.1

Nordic mountain birch ecosystem in the future, but probably the greatest change in this system will be the degree of tourism permitted in the region, as influenced by the future infrastructure.

The possibilities for sustainable use of the Nordic mountain birch ecosystem are evaluated in various models presented in the volume, giving answers based on the scenarios chosen. However, it is NOT the aim of the volume to present a preferred future in the Nordic mountain birch ecosystem. That is up to the politicians and other decision-makers to determine, but the chapters in this volume have been planned to make it possible to choose the best solutions in various countries and districts. However, it is recommended that decisions should be made in cooperation with the local people in a district, and should not be made SOLELY by the central authorities in the various districts.

It is very valuable for the Nordic scientists working in the mountain birch regions to present various results from an interdisciplinary and integrated project, including social scientific subprojects, all together in a new volume of the series Ecological Studies as a sort of continuation of the results presented partly from the same region in the same series about 30 years ago. The editor thanks the publisher for making this possible and is very glad to have all these Nordic mountain birch data presented in one place.

October 2004 *F. E. Wielgolaski*
Oslo, Norway

Acknowledgement. The HIBECO project was financed by EU 5th Framework Program.

References

Aradottir AL, Arnalds O (2001) Ecosystem degradation and restoration of birch woodlands in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 293–306

Wielgolaski FE (ed) (1975a) Fennoscandian tundra ecosystems, part 1. Plants and microorganisms. Ecological studies 16. Springer, Berlin Heidelberg New York

Wielgolaski FE (ed) (1975b) Fennoscandian tundra ecosystems, part 2. Animals and systems analysis. Ecological studies 17. Springer, Berlin Heidelberg New York

Wielgolaski FE (ed) (2001) Nordic mountain birch ecosystems. MAB series 27. UNESCO, Paris and Parthenon, New York

Contents

Section 1 History, Environment and Plant Science

1 History and Environment of the Nordic Mountain Birch . . 3
F.E. Wielgolaski

1.1 History–Zonation–Taxonomy–Distribution 3
1.2 Present Tree Line 4
1.3 Climate 7
1.4 Nutrient Conditions – Browsing 12
References 15

2 Soils and Nutrients in Northern Birch Forests: A Case Study from Finnmarksvidda, Northern Norway . . . 19
K.-D. Meier, D. Thannheiser, J. Wehberg and V. Eisenmann

2.1 Introduction 19
2.2 Study Area 20
2.3 Soil Classification 21
2.4 Soil Distribution 23
2.5 Soil Properties 28
2.6 Conclusions 31
References 32

3 Vegetation of the Mountain Birch Forest in Northern Fennoscandia 35
J. Wehherg, D. Thannheiser and K.-D. Meier

3.1 Introduction 35
3.2 Study Site 36

3.3 Dendrochronological Characteristics of the Northern Mountain Birch Forests in the Máze-Kautokeino Area 36
3.4 Plant Sociological Studies 40
3.4.1 The Communities of the Mountain Birch Forest on the Finnmarksvidda 41
3.4.1.1 The Crowberry Birch Forest: *Empetro-Betuletum pubescentis* (Nordhagen 1943) 44
3.4.1.2 The Lingonberry Birch Forest: *Vaccinio vitis-idaeae-Betuletum* (prov.) 45
3.4.1.3 The Bilberry Birch Forest: *Vaccinio myrtilli-Betuletum* (prov.) 46
3.4.1.4 The Dwarf Cornel Birch Forest: *Corno-Betuletum* (Aune 1973) 46
3.4.1.5 The Meadow Birch Forest: *Geranio-Betuletum* (Nordhagen 1928, 1943 emend. Dierßen and Dierßen 1982) 47
3.4.1.6 The Cloudberry Birch Forest: *Rubo chamaemorei-Betuletum* (prov.) 48
3.5 Mountain Birch Forests in Northern Fennoscandia 49
3.6 Conclusions 49
References 51

4 Biomass and Production on a Landscape Level in the Northern Mountain Birch Forests 53
H. Tømmervik, F.E. Wielgolaski, S. Neuvonen, B. Solberg and K.A. Høgda

4.1 Introduction 53
4.1.1 Live Aboveground Biomass Estimations 55
4.1.2 Biomass and Leaf Area Index at Individual Tree or Stand Levels 56
4.1.3 Biomass on Landscape and Regional Level Using Remote Sensing 57
4.2 Methods 58
4.3 Results 61
4.3.1 Change in the Biomass Production on a Regional Level . . . 61
4.3.2 Biomass Estimations on a Landscape Level 62
4.4 Discussion 64
4.4.1 Biomass Changes 64
4.4.2 Remote Sensing Data – Are They Robust? 66
References 67

5 Mountain Birch Growth in Relation to Climate and Herbivores . . . 71
P.S. Karlsson, M. Weih and C. Borg

5.1 Introduction . . . 71
5.2 Seedling Establishment and Growth . . . 72
5.2.1 Abiotic and Biotic Environment During the Growing Season 72
5.2.2 Winter Conditions . . . 74
5.2.3 Genetic Aspects . . . 74
5.3 Sapling Growth . . . 75
5.4 Mature Trees . . . 76
5.4.1 Tree Growth and Climate . . . 76
5.4.2 Effects of *Epirrita* Defoliation on Tree Growth . . . 77
5.5. Forest Structure, Stand Biomass and Productivity . . . 79
5.6. Effects of Changing Climate on Mountain Birch Growth . . 81
5.6.1 Empirical Evidence . . . 81
5.6.2 Model Predictions . . . 82
5.7 Conclusions . . . 82
References . . . 83

6 Responses of Temperature Changes on Survival and Growth in Mountain Birch Populations . . . 87
O. Skre, J. Nilsen, M. Naess, B. Igeland, K. Taulavuori, E. Taulavuori and K. Laine

6.1 Introduction . . . 87
6.2 Results and Discussion . . . 89
6.2.1 Field and Greenhouse Experiments at Different Temperatures . . . 89
6.2.2 Winter Temperature and CO_2 Experiments . . . 93
6.2.3 Dormancy and Frost Hardiness in Mountain Birch Provenances as Influenced by Winter Temperatures . 94
6.3 Conclusions . . . 96
References . . . 96

7 **Phenology and Performance of Mountain Birch Provenances in Transplant Gardens: Latitudinal, Altitudinal and Oceanity–Continentality Gradients** 99
J. Ovaska, J. Nilsen, F.E. Wielgolaski, H. Kauhanen, R. Partanen, S. Neuvonen, L. Kapari, O. Skre and K. Laine

7.1 Introduction 99
7.2 Material and Methods 101
7.3 Results and Discussion 101
7.3.1 Transplantation Stress and Seedling Survival 101
7.3.2 Spring Phenology (Bud Burst) 103
7.3.3 Autumn Phenology 106
7.3.4 Growth Forms and Growth Rates 108
7.4 Conclusions and Future Prospects 113
References 114

8 **Synthesis Section 1: A Dynamic Forest in a Changing Environment** 117
P.S. Karlsson and F.E. Wielgolaski

References 121

Section 2 Herbivory

9 **Forest Defoliation Risks in Birch Forests by Insects Under Different Climate and Land Use Scenarios in Northern Europe** 125
S. Neuvonen, H. Bylund and H. Tømmervik

9.1 Introduction 125
9.2 Geometrid Outbreaks on Birch in Fennoscandia 126
9.3 Monitoring (Detecting/Quantifying) Insect Outbreaks in Mountain Birch Woodlands 127
9.4 Modelling the Outbreak/Defoliation Risks 129
9.4.1 Population Dynamics of Geometrid Moths 129
9.4.2 Modelling the Regional and Topographic Patterns in Outbreaks Risks 131
9.5 Forest Defoliation Risks Under Different Climatic Scenarios and Their Relationships to Land Use 134
References 136

10 Birch Sapling Responses to Severity and Timing of Domestic Herbivore Browsing – Implications for Management 139
A.J. Hester, K. Lempa, S. Neuvonen, K. Høegh, J. Feilberg, S. Arnthórsdóttir and G. Iason

10.1 Introduction 139
10.2 Case Studies and Experimental Designs 141
10.3 Birch Responses to Timing and Severity of Browsing Damage 141
10.3.1 Severity of Browsing 142
10.3.2 Timing of Browsing 145
10.3.3 Locational Effects 145
10.3.4 Implications for the Management of Herbivore Grazing Within Birch Areas of Northern Europe 146
10.4 Theory Versus Reality: Case-Study Example of Sheep Impacts in Greenland 147
10.4.1 Economics 150
10.5 Current Activities to Improve Grazing Management in Birch Forest Areas 151
10.6 Conclusions 152
References 153

11 Effects of Reindeer Grazing on Pastures in a Mountain Birch Ecosystem 157
K. Lempa, S. Neuvonen and H. Tømmervik

11.1 Introduction 157
11.2 Climatic Variability 158
11.3 Trends and Patterns in Reindeer Population Densities in Northern Fennoscandia 159
11.4 Protection of Pastures in the Mountain Birch Zone 160
11.4.1 Analysis and Synthesis of the Effects of Reindeer Grazing on Different Vegetation Components 160
11.4.2 Northernmost Norway as a Case Study of the Overall Effects of Reindeer Grazing on Vegetation . . 163
References 164

12 **Long-Term Influence of Herbivores on Northern Birch Forests** 165
O. Tenow, H. Bylund, A.C. Nilsen and P.S. Karlsson

12.1 Introduction 165
12.2 Lake Torneträsk–Abisko Valley Area: A Case Study 166
12.2.1 Outbreak in a Heath Birch Forest 166
12.2.2 Outbreak in a Meadow Birch Forest 168
12.3 Northern Fennoscandia 169
12.3.1 Forest Age and Outbreaks 170
12.3.2 Forest Damage and Recovery 170
12.3.3 Interaction with Reindeer and Sheep 172
12.4 Generalization 173
12.4.1 A Conceptual Model 174
12.4.2 Forests Without Outbreaks 175
12.4.3 Mountain Birch Forest Regeneration Cycles in a Warmer Future 176
References 178

13 **Synthesis Section 2: Herbivory in Northern Birch Forests** . 183
S. Neuvonen and F.E. Wielgolaski

13.1 Introduction 183
13.2 Insect Outbreaks 185
13.3 Mammalian Herbivores 186
13.4 Implications for Sustainable Management 187
13.5 References 188

Section 3 Human Impact

14 **Rates and Processes of Natural Regeneration in Disturbed Habitats** 193
B.C. Forbes, A. Tolvanen, F.E. Wielgolaski and K. Laine

14.1 Introduction 193
14.2 Processes of Regeneration 195
14.3 Rates of Regeneration 197
14.4 Conclusion 199
References 199

15 Recreation at the Tree Line and Interactions with Other Land Use Activities 203

A. Tolvanen, B.C. Forbes, S. Wall and Y. Norokorpi

15.1 Introduction 203
15.2 Case Study Areas 205
15.3 Monitoring Studies on the Impact of Recreation on the Environment in Lapland 207
15.4 Interaction of Recreation with Other Land-Use Activities . . 209
15.4.1 Recreation vs. Nature Conservation 210
15.4.2 Recreation vs. Forestry 211
15.4.3 Recreation vs. Traditional Livelihoods 211
15.4.4 Recreation vs. Recreation 213
15.5 Sustainable Tourism 213
References 214

16 Economic Limits and Possibilities for Sustainable Utilization of Northern Birch Forests 219

B. Solberg, H. Tømmervik, D. Thannheiser and S. Neuvonen

16.1 Introduction 219
16.2 Some Theoretical Aspects 219
16.2.1 Goals 220
16.2.2 Sustainable Utilization 220
16.2.3 Identify Utilization Alternatives 221
16.2.4 Select the Best Utilization (Management) Alternative 221
16.2.5 Implementation of the Best Alternatives 221
16.3 Empirical Results 222
16.3.1 Birch Area and Productivity 222
16.3.1.1 Máze 223
16.3.1.2 Målselv 225
16.3.1.3 Other Areas 225
16.3.2 Reindeer Husbandry 226
16.3.3 Other Limiting Factors 228
16.3.4 Profitability, Value Added and Markets 228
16.4 Conclusions 231
References 232

17 The Vegetation Changes and Recent Impact on the Mountain Birch Forest During the Last 40 Years . . . 235
D. Thannheiser, H. Tømmervik and J. Wehberg

17.1 Introduction 235
17.1.1 Research Areas 236
17.1.2 Methodological Considerations 236
17.2 Vegetation Changes in the Máze Region 237
17.2.1 The Lichen-Rich *Empetrum* (Crowberry) Birch Forest (*Empetro-Betuletum pubescentis*; see Chap. 3) . 237
17.2.2 The Moss-Rich *Empetrum* (Crowberry) Birch Forest (*Empetro-Betuletum pubescentis*, see Chap. 3) 240
17.2.3 The Lichen-Rich *Myrtillus* (Bilberry) Birch Forest (*Vaccinio myrtilli-Betuletum*; see Chap. 3) 240
17.2.4 The Moss-Rich *Myrtillus* (Bilberry) Birch Forest (*Vaccinio myrtilli–Betuletum*; see Chap. 3) 241
17.2.5 The *Cornus–Myrtillus* (Dwarf Cornel–Bilberry) Birch Forest (*Corno-Betuletum*; see Chap. 3) 241
17.2.6 Monitoring Vegetation Change in the Máze Region 241
17.2.7 Monitoring Vegetation Change in Målselv 244
17.2.8 Discussion 246
17.3 Linear and Localized Development on the Finnmarksvidda 250
References 252

18 Sámi Approaches to Mountain Birch Utilization in Northern Sápmi (Finland and Norway) 255
M.S. Aikio and L. Müller-Wille

18.1 Introduction: Control, Access and Sustainability of Mountain Birch Forests 255
18.2 Human–Birch Relations: Holistic Approach to the Environment 257
18.3 Knowledge and Values: The Meaning and Use of Mountain Birch 259
18.3.1 Birch Firewood: Securing Heat and Warmth 260
18.3.2 The Proper Mountain Birch Wood for Art and Handicraft . 262
18.4 The Human Factor: Future Management of Mountain Birch Resources 264
18.5 Outlook: Prospects and Policy Recommendations 266
References 268

19 Sustainable Reindeer Herding in the Mountain Birch Ecosystem 269
K. Lempa, S. Neuvonen and H. Tømmervik

19.1 Introduction 269
19.2 History 269
19.3 Cultural Background 270
19.4 Social and Economical Factors 271
19.5 Suggestions 272
References 273

20 Synthesis Section 3: Competition over Nature, Space, Resources, and Management in the Northern Mountain Birch Forest Ecosystem 275
D. Thannheiser, L. Müller-Wille, F.E. Wielgolaski and K.-D. Meier

Section 4 Modelling Dynamics of Mountain Birch Forests, Management and Future

21 Landscape-Scale Model Relating the Nordic Mountain Birch Forest Spatio-temporal Dynamics to Various Anthropogenic Influences, Herbivory and Climate Change 283
A.O. Gautestad, F.E. Wielgolaski and I. Mysterud

21.1 Introduction 283
21.2 Complexity Aspects in the Northern Birch Forest Ecosystem 284
21.2.1 Aspect 1: Challenges from Quantity of Interactions – System Complexity 284
21.2.2 Aspect 2: Processes in Linear Superposition – Scale-Specific Spatio-Temporal Interactions 285
21.2.3 Aspect 3: Beyond Superposition – Spatio-Temporal Effects from Non-Linear Responses 288
21.3 The HIBECO Model 289
21.3.1 The Model Arena 290
21.3.2 Implementation of Landscape Heterogeneity 291
21.3.3 Management Regimes and Perturbations 292
21.3.4 Climate Change Scenarios 293
21.4 Simulation Examples 295
21.5 Discussion and Conclusions 298
References 299

22 Scenarios for Future Development of the Mountain Birch Ecosystem 301
A.O. Gautestad, F.E. Wielgolaski, B. Solberg and I. Mysterud

22.1 Introduction 301
22.2 Logging Practices and the Shifting Forest Mosaic 302
22.3 Scenarios for Various Long-Term Management Practices . . 305
22.4 Discussion and Conclusion 310
References 311

23 Managing the Mountain Birch Ecosystem: Local Communities and the State in Finland's Forestry . . . 313
L. Müller-Wille, M.S. Aikio and V. Luhta

23.1 Introduction: Resource for Wood and Energy 313
23.2 Forests and Wood: Issues of Power and Control 316
23.3 Current Practices and Perceptions of Mountain Birch Utilization 317
23.3.1 Management and Production of Private Birch Woodlots . . 319
23.3.2 Management and Production of Public Birch Forests 320
23.3.3 Perception and Assessment of Mountain Birch Forest Management 322
23.4 The Mountain Birch – A Resource in the Future? 324
References 326

24 Policies and Developing Plans Towards Sustainability of Mountain Birch Ecosystems in Scandinavia 327
L. Bäck, B. Solberg, H. Tømmervik and F.E. Wielgolaski

24.1 Introduction 327
24.2 Suggestions for Sustainable Reindeer Management 328
24.3 The Mountain Birch Forest from a Multi-User Perspective . 329
24.4 The Human View on Mountain Nature 333
24.5 Visitor Frequency in Nature 334
25.6 Different Planning Strategies for Sustainable Development in the Mountains 334
24.7 The Need for Scientific Pluralism 336
24.8 Suggestions for Sustainable Forest Management 338
References 339

Section 5 Integration and Conclusion

25 The Nordic Mountain Birch Ecosystem-Challenges to Sustainable Management 343
F.E. Wielgolaski, P.S. Karlsson, S. Neuvonen, D. Thannheiser, H. Tømmervik and A.O. Gautestad

25.1 Introduction 343
25.2 Man and Mountain Birch Forest Interactions in the Perspective of a Changing Climate 345
25.3 Considerations for Sustainable Mountain Birch Forest Management 347
25.4 Considerations for a Sustainable Reindeer Management . . 353
25.5 Final Remarks 354
References 355

Subject Index 357

CD-ROM containing additional material to Chapters 2, 3, 7, 10, 11, 18, 21, and 22 enclosed at the end of the book

Contributors

Aikio, M.S.

Suoma sámiid guovddášsearvi (Finnish Sámi Association), Suohpajávri –
A 777 Ohcejohka, 99800 Ivalo/Avvil, Finland, e-mail: sofia.aikio@luukku.com

Arnthórsdóttir, S.

Icelandic Institute of Natural History, Akureyri Division, Hafnarstræti 97,
P.O. Box 180 602, Akureyri, Iceland

Bäck, L.

Department of Social Sciences, Mid Sweden University, 83125 Östersund,
Sweden, e-mail: lennart.back@mh.se

Borg, C.

Department of Plant Ecology, Evolutionary Biology Centre, Uppsala
University, Villavägen 14, 75236 Uppsala, Sweden

Bylund, H.

Department of Entomology, Swedish University of Agricultural Sciences,
P.O. Box 7044, 75007 Uppsala, Sweden, e-mail: helena.bylund@entom.slu.se

Eisenmann, V.

Institute of Soil Science, Hamburg University, Allende-Platz 2,
20146 Hamburg, Germany, e-mail: v.eisenmann@podsol.de

Feilberg, J.

Biomedia, Kastrupvej 8, 4100 Ringsted, Denmark

Forbes, B.C.

Arctic Centre, University of Lapland, P.O. Box 122, 96101, Rovaniemi,
Finland, e-mail: bforbes@ulapland.fi

Gautestad, A.O.

Department of Biology, University of Oslo, P.O. Box 1050 Blindern, 0316 Oslo, Norway, e-mail: a.o.gautestad@bio.uio.no

Hester, A.J.

Macaulay Institute, Craigiebuckler, Aberdeen AB15 8QH, UK,
e-mail: a.hester@macaulay.ac.uk

Høegh, K.

Greenland Agricultural Advisory Service, P.O. Box 153, 3920 Qaqortoq, Greenland, e-mail: savacon@greennet.gl

Høgda, K.A.

Earth Observation Group, Norut Information Technology, 9291 Tromsø, Norway, e-mail: kjell-arild.hogda@itek.norut.no

Iason, G.

Macaulay Institute, Craigiebuckler, Aberdeen AB15 8QH, UK

Igeland, B.

Department of Biology, University of Tromsø, 9037 Tromsø, Norway

Kapari, L.

Kevo Subarctic Research Institute, University of Turku, 20014 Turku, Finland

Karlsson, P.S.

Department of Plant Ecology, Evolutionary Biology Centre,
Uppsala University, Villavägen 14, 75236 Uppsala, Sweden, e-mail:
staffan.karlsson@ebc.uu.se

Kauhanen, H.

Kolari Research Station, Finnish Forest Research Institute, 95900 Kolari, Finland, e-mail: heikki.kauhanen@metla.fi

Laine, K.

Botanical Gardens, University of Oulu, P.O. Box 333, 90571 Oulu, Finland,
e-mail: kari.laine@oulu.fi

Lempa, K.

Kevo Subarctic Research Institute, University of Turku, 20014 Turku, Finland and Departmentfo Applied Biology, University of Helsinki, 00014 Helsinki, Finland, e-mail: kyosti.lempa@pp.nic.fi

Luhta, V.
P.O. Box 115, 99801 Ivalo, Finland

Meier, K.-D.
PPA 2, Otsontie 1, 95980 Ylläsjärvi, Finland

Müller-Wille, L.
Department of Geography, McGill University, Burnside Hall 705,
805, rue Sherbrooke Ouest, Montréal (Québec), H3A 2K6 Canada,
e-mail: ludger.muller-wille@mcgill.ca

Mysterud, I.
Department of Biology, University of Oslo, P.O. Box 1050 Blindern, 0316 Oslo,
Norway, e-mail: ivar.mysterud@bio.uio.no

Naess, M.
Interpro AS, Kokstadflaten 4b, 5061 Kokstad, Norway

Neuvonen, S.
Kevo Subarctic Research Institute, University of Turku, 20014 Turku,
Finland, e-mail: sepne@utu.fi

Nilsen, J.
Department of Biology, University of Tromsø, 9037 Tromsø, Norway,
e-mail: jarle.nilsen@ibg.uit.no

Nilssen, A.C.
Tromsø Museum, University of Tromsø, 9037 Tromsø, Norway

Norokorpi, Y.
Finnish Forest and Park Service, Northern Lapland District, Pallaksentie
1961, 99300 Muonio, Finland, e-mail: yrjo.norokorpi@metsa.fi

Ovaska, J.A.
Kevo Subarctic Research Institute, University of Turku, 20014 Turku, Finland

Partanen, R.
Kilpisjärvi Biological Station, University of Helsinki, P.O. Box 17,
00014 Helsinki, Finland

Skre, O.
Skogforsk Bergen, 5244 Fana, Norway, e-mail: oddvar.skre@skogforsk.no

Solberg, B.

Department of Ecology and Natural Resource Management,
Agricultural University of Norway, P.O. Box 5003, 1432 Ås, Norway,
e-mail: birger.solberg@ina.nlh.no

Taulavuori, E.

Institute of Biology, University of Oulu, P.O. Box 3000, 90014 Oulu, Finland

Taulavuori, K.

Institute of Biology, University of Oulu, P.O. Box 3000, 90014 Oulu, Finland

Tenow, O.

Department of Entomology, Swedish University of Agricultural Sciences,
P.O. Box 7044, 75007 Uppsala, Sweden, e-mail: olle.tenow@swipnet.se

Thannheiser, D.

Department of Geography, Hamburg University, Bundesstr. 55,
20146 Hamburg, Germany, e-mail: thannheiser@geowiss.uni-hamburg.de

Tømmervik, H.

Norwegian Institute for Nature Research, Polarmiljøsenteret, 9296 Tromsø,
Norway, e-mail: hans.tommervik@nina.no

Tolvanen, A.

Finnish Forest Research Institute, Muhos Research Station,
Kirkkosaarentie 7, 91500 Muhos, Finland, e-mail: anne.tolvanen@metla.fi

Wall, S.

Department of Human Geography and European Tourism Research Institute
(ETOUR), Mid Sweden University, 83125 Östersund, Sweden,
e-mail: sandra.wall@mh.se

Wehberg, J.

Department of Geography, Hamburg University, Bundesstr. 55,
20146 Hamburg, Germany, e-mail: wehberg@geowiss.uni-hamburg.de

Weih, M.

Department of Short Rotation Forestry, Agricultural University of Sweden,
P.O. Box 7016, 75007 Uppsala, Sweden, e-mail: martin.weih@lto.slu.se

Wielgolaski, F.E.

Department of Biology, University of Oslo, P.O. Box 1045 Blindern, 0316 Oslo,
Norway, e-mail: f.e.wielgolaski@bio.nio.no

Section 1

History, Environment and Plant Science

1 History and Environment of the Nordic Mountain Birch

F.E. Wielgolaski

1.1 History-Zonation-Taxonomy-Distribution

Birch is an old inhabitant of the Nordic countries as shown both by palynology and radiocarbon dating of subfossil birch remnants. Woody vegetation, not very different from the present-day mountain birch trees/shrubs in subalpine and northern Fennoscandia, migrated rapidly into the region after the last glacial period, probably first into southwestern Norway 12,000 B.P. (Aas and Faarlund 2001), and to the northernmost part of the region (ca. 71°N) approximately 1000 years later (however, cf. Chap. 2).

The upper and northern tree line has varied with the climate through the centuries ever since. The historical highest tree line in southern Fennoscandia, about 500 m above today's limit, has been dated back to more than 10,000 B.P., using mega-fossil evidence and radiocarbon dating (Kullman and Kjällgren 2000), only about 1000 years after birch had reached northernmost Fennoscandia. In the boreal chronozone about 8500 B.P., birch also reached high elevations (Moe et al. 1978).

The Nordic tree line zone is mainly dominated by what we normally call the northern mountain birch today (Wielgolaski 2002), and generally covers the ecotone between the coniferous forest zone and the treeless areas in the Nordic countries. It is most often referred to as the subalpine zone, which also forms a substantial part of the northern boreal zone (Moen 1999). The zone was first described by Wahlenberg (1812) and includes both the area with birch towards the northern or arctic tree line and towards the maritime tree line mainly to the west, in addition to the tree line towards the alpine zone in the mainly N–S running mountain chain almost throughout the length of the Nordic countries. Similar limits for Nordic mountain birch forests apply today (Hämet-Ahti 1963), particularly in Finland, also called the upper oroboreal zone (Ahti et al. 1968; Haapasaari 1988). However, the delimitation of western and northern Fennoscandia is complicated in places by the local climatic diversity, due to greatly varying topography of the mountain areas and the

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

fjords along the coast. Together with edaphic variations, these conditions are responsible for the often diffuse character of the limits of the Nordic birch zone (Haapasaari 1988).

The taxonomy of Nordic mountain birch is difficult and unclear. In its typical form this birch is dominant in the eastern Kola Peninsula and throughout subalpine regions of the Fennoscandian mountain chain. Genes from the dwarf shrub *Betula nana* L. are strongly involved in the Nordic mountain birch (Thórsson et al. 2001), and are sometimes visually shown by small leaves and bright red autumn colours (Nilsen and Wielgolaski 2001). Today, this often polycormic birch is treated as a subspecies of *B. pubescens* Ehrh. called ssp. *czerepanovii* (Orlova) Hämet-Ahti (often also called *B.p.* ssp. *tortuosa* auct. or even *B. tortuosa* Led., a name which today is usually limited to a birch growing in the Altai mountains).

Birch is the only native tree species commonly growing in Iceland. It is also treated as a Nordic mountain birch by most authors today, although it is clearly a specific ecotype compared to the Fennoscandian mountain birch (see e.g., Wielgolaski and Nilsen 2001). Väre (2001) reported that the birch in Iceland has appeared independently of the formation in Fennoscandia, but it is likely the mountain birch has a polytopic history in both regions with introgressive hybridization of *B. nana* where this flowers more or less simultaneously with the other.

The typical *B. pubescens*, often called ssp. *pubescens*, has few, if any, genes from *B. nana.* The subspecies is normally found in richer soil at lower elevation, e.g., in valley bottoms, and at lower latitudes, commonly with only one stem (monocormic). This is generally the type found in Scotland. Sometimes the closely related birch growing in southwestern Greenland is also treated as a Nordic mountain birch, although there is often strong hybridization with the American *B. glandulosa* Michx.

Birch is also found east of the Kola Peninsula, but the taxonomy is very unclear, and many taxa may be involved. Low temperature is suggested to reduce the genetic incompatibility between various birch taxa (Hagman 1971). In this volume, the mountain birch from Fennoscandia, Iceland, Greenland and Scotland is discussed. *B. pendula* Roth. is most common in the southern parts of the region and hybridizes with the Nordic mountain birch, however, it is not included in this project.

1.2 Present Tree Line

Today, the upper mountain birch tree line is above 1200 m a.s.l. in central southeastern Norway (Fig. 1.1), but it is lower in all directions moving away from that district, strongly lower towards the southwest coast of Norway (ca. 500 m a.s.l.), and eastwards in Sweden at similar latitudes (900–800 m a.s.l.).

Fig. 1.1. Map of the upper climatic tree line in Fennoscandia as given by hypsogrammetric curves in solid lines. (Aas and Faarlund 2001)

The birch tree line is also lower to the north, but in inner Scandinavia, at the Arctic Circle, it may still be 700–800 m a.s.l. (Aas and Faarlund 2001). Near the sea in the far north of Fennoscandia it descends dramatically, nearly to sea level at about 71°N, (however, cf. Chap. 2).

Presently, there are several indications for slowly increasing Nordic mountain birch tree lines in the region (Sonesson and Hoogesteger 1983; Kullman 2000, 2002), which are at least partly attributable to a general climate change, but also to human use of the mountain birch forests, particularly reduced grazing by domestic animals. In many places, it has been observed that the mountain birch forest near the forest line grows more vigorously than just a few decades ago (own unpubl. observ.). This is also the case above the height reached for browsing by animals. The tree crowns seem to be considerably denser than they were earlier. This could be a consequence of a better climate for birch tree growth (cf. Kullman 2000). It has also been noted that the extended birch forest towards the tree line is surprisingly even-aged. Could this be because seedlings suddenly were strong enough to survive in a better climate and could grow above the winter snow cover?

Both historically and more recently, man has strongly influenced the presence of birch by logging, e.g. for fuel and by strong animal grazing. On the Faroe Islands native birch has totally disappeared, probably due to the disturbance by man (Aas and Faarlund 2001). In Iceland there has been a strong degradation of birch forests due to anthropogenic influence (Aradottir and Arnalds 2001) since the Viking settlements late in the ninth century. It is, therefore, difficult to define the climatic tree line of Iceland today. Thorhallsdottir (1997) reported that it may be close to 300 m in coastal regions, but up to about 550 m elevation in inland areas, particularly in the northeast.

It has often been discussed why birch is the main tree line species in the Nordic countries (e.g. Oksanen 1995), while in most regions of the world the tree line is formed by coniferous species (e.g. Walter 1974). Ahti and Hämet-Ahti (1969) stressed that timberline forests dominated by birches and other mesomorphic deciduous trees are typical for high-latitude areas adjacent to ice-free oceans. This indicates that the degree of oceanity plays a role in why birch is the main tree line species in the Nordic countries. The author has found in phenology studies in western Norway that high humidity favours the time of leaf bud break more in birch than in most other deciduous trees studied (Wielgolaski 2003).

In the southeastern districts of the Caledonian mountain chain in Scandinavia, which are the most continental parts of the region, there are pockets of spruce at the tree line (own observ.). Again, this indicates humidity as one factor of importance for which tree species dominates the tree line. However, there is also a possibility that strong grazing has caused the upper birch tree line to be depressed. On the other hand, this should also favour coniferous trees at the tree line in more humid districts and in inner, relatively continental districts of northern Fennoscandia, which is generally not found (Oksanen 1995). The last author has presented various hypotheses for the development of certain species to be dominant at the tree line. He suggested that rain shadow areas relatively close to open oceans might be characterized by a mixture of oceanic and continental factors maximally disadvantageous for evergreens, leading to respiratory losses in winter and soil frost-induced drought stress in spring. However, he also followed the hypothesis by, e.g. Fægri (1950), that a dispersal barrier prevented spruce from reaching all areas that otherwise would have fitted the species, and that this is a possibility for the lack of spruce in some Fennoscandian mountain areas. Oksanen (1995) further mentioned the possibility that spruce may have problems defending positions obtained for instance in northernmost Fennoscandia during the historical hypsithermal period and expanding the range under current climatic conditions. On the other hand, elevationally increased tree lines are documented also for coniferous trees at increased temperature by global change (Hofgaard 1997; Kullman 2000, 2002).

1.3 Climate

The growth of Nordic mountain birch is thus, like most other plants species in temperate regions, strongly dependent on temperature and heat sums above certain basic or threshold temperatures in the growing season (Wielgolaski 1999). Odland (1996) found the best correlation with the upper Nordic mountain birch forest line to be with the average maximum temperature isotherm 13.2 °C of the four warmest summer months (tetratherm), although this is not a vital survival limit for birch. The survival of browsing insects, however, is dependent on the minimum winter temperatures (see Chaps. 9 and 12). Helland (1912) already calculated the mountain birch tree line to follow the 7.3 °C tetratherm for the mean diurnal temperature and the coniferous tree line the tetratherm of 8.3 °C. If we compare the present birch tree line with calculated temperature normals near the birch forest limit, e.g. at Kvamskogen, Haugastøl, Fokstua, Bjørnfjell and Kilpisjärvi (Table 1.1), it seems that the birch forest limit is closer to the 8 °C tetratherm. However, mean temperature limits decrease in relatively continental areas with high day temperatures during summer (Wielgolaski 1975) and may increase in more oceanic districts, e.g. Kvamskogen (Tables 1.1–1.2).

Kullman (2000) stressed that the tree height growth increased markedly in the period 1988–1999 with slightly higher (0.3 °C) summer temperatures than the preceding period 1951–1987. He also observed that individual trees, which had been suppressed during the low temperatures in the last-mentioned period, responded by serious winter dieback at the approx. 2.6 °C increase in mean winter temperatures combined with the higher summer temperatures in 1988–1999. In the most probable global change temperature scenarios, meteorologists have suggested that temperatures in Fennoscandia will continue to increase in the period up to 2050 by about 0.4 °C per decade in the north (Hanssen-Bauer et al. 2000).

Although temperature is the most important climatic factor for growth of the Nordic mountain birch, humidity, as mentioned before, also has an influence. The annual precipitation varies greatly in Fennoscandia, from about 300 mm east of the Scandes (Table 1.2) to considerably more than ten-fold in coastal mountains of southwestern Norway. Particularly high precipitation is observed at higher elevations just west of the highest mountain massifs because of the uplift and cooling of the mainly southwesterly winds and cyclonic movements in Fennoscandia. The precipitation is somewhat lower close to the sea in the west and decreases to the far north. Even at the northeasternmost coast of Norway it is often less than 400 mm/year (e.g. Ekkerøy Table 1.2), but fog and drizzle are common.

In precipitation scenarios, the precipitation is normally supposed to increase in the Nordic mountain birch region up to year 2050 (Hanssen-Bauer et al. 2001). This has been estimated particularly for the northwestern coast

Table 1.1. Normal temperature (mean °C). (Kärenlampi 1972; Järvinen 1987; Alexandersson et al. 1991; Lippestad 2003)

Coordinates °N–S; °E–W	Height (m)	Site	Period March	April	May	June	July	Aug.	Sept.	Year	Mean June–Sept.
60.5; 5.5	408	Kvamskogen	−0.8	2.0	7.0	10.9	11.9	11.6	8.4	4.1	10.7
60.5; 8.0	988	Haugastøl	−6.8	−2.8	2.9	7.8	9.8	9.2	5.2	−0.2	8.0
62.1; 9.3	952	Fokstua	−7.0	−2.9	3.8	8.4	10.0	8.9	4.4	−0.7	7.9
62.5; 12.1	680	Fjällnäs	−6.7	−2.4	4.0	9.0	10.5	9.4	5.2	−0.4	8.5
63.2; 12.0	642	Storlien	−4.6	−1.3	4.6	9.3	10.7	10.0	6.0	1.1	9.0
65.5; 16.5	652	Danasjö	−6.9	−2.5	3.6	9.4	11.2	9.5	4.7	−0.6	8.5
66.5; 16.3	500	Vuoggatjolme	−8.7	−2.7	3.4	9.0	11.4	9.9	5.3	−1.7	8.9
67.1; 18.2	530	Aktse	−7.8	−2.6	3.6	9.4	11.6	9.7	4.5	−1.4	8.8
68.3; 18.8	388	Abisko	−8.0	−2.7	3.2	8.4	11.0	9.7	5.2	−0.8	8.3
68.4; 18.1	512	Bjørnfjell	−8.5	−4.0	1.8	7.0	10.5	9.2	4.2	−1.6	7.7
68.5; 14.5	10	Melbu (Bø)	−0.8	1.6	5.2	9.3	11.5	11.5	8.0	4.1	10.1
69.0; 20.8	500	Kilpisjärvi	−10.0	−4.9	1.3	7.2	10.6	9.1	4.4	−2.6	7.8
69.0; 23.2	330	Kautokeino	−10.6	−4.1	2.9	9.7	12.4	10.2	4.8	−2.5	9.3
69.7; 27.0	110	Kevo	−11.0	−3.4	2.8	9.2	11.8	10.2	5.4	−2.4	9.2
70.2; 30.1	6	Vardø (Ekkerøy)	−4.9	−1.1	3.1	7.3	10.4	10.5	6.8	1.4	8.7

Table 1.2. Normal precipitation (sum mm). Site specifications and references, see Table 1.1

Sum (mm) Site	Period March	April	May	June	July	Aug.	Sept.	Year	June–Sept.
Kvamskogen	254	138	145	180	188	237	392	3151	997
Haugastøl	53	29	46	62	70	72	73	710	277
Fokstua	28	17	28	55	61	52	42	450	210
Fjällnäs	46	44	49	74	95	85	97	812	351
Storlien	47	48	45	75	105	92	115	857	387
Danasjö	41	32	46	59	102	84	75	697	320
Vuoggatjolme	28	18	27	39	87	58	51	512	235
Aktse	33	32	42	54	97	94	78	664	323
Abisko	15	12	13	22	54	45	23	304	144
Bjørnfjell	52	48	45	70	87	99	98	940	354
Melbu (Bø)	66	57	58	62	81	70	118	970	331
Kilpisjärvi	24	17	22	39	64	51	40	422	194
Kautokeino	9	11	19	38	69	59	43	325	209
Kevo	17	19	18	41	78	66	39	422	224
Vardø (Ekkerøy)	27	21	21	23	48	39	31	373	141

and in the autumn (nearly 6 % increment in the precipitation is predicted per decade for that district in the autumn), while it has only been predicted to increase half as much in the more continental, inner part of Fennoscandia. Here, however, the increment is predicted to be nearly as high in spring in the scenarios. Much of the increased precipitation at that time of the year may come as snow in the mountains and in the inner northern Fennoscandia, which will also influence the time of snow melt and onset of spring (Högda et al. 2001). The soil moisture, therefore, is expected generally to be higher than before in early summer, which influences the vegetation.

At present, more suboceanic species in inner northern Norway have been observed than before in inner northern Norway (see Chaps. 3, 4, 17,). Mountain birch generally needs good moisture conditions for germination. Increased soil moisture may, therefore, increase the seed propagation of birch. This may be one reason for the larger cover of birch in northern Fennoscandia in recent years (see Chap. 17). Birch has a wide and dense root net with large roots observed more than 25 m from the trunk (e.g. Laitakari 1935; own unpubl. results). It takes more water from the soil than most other trees of the same size and age. The daily transpiration rate is in the order of 8–10 g/g fresh

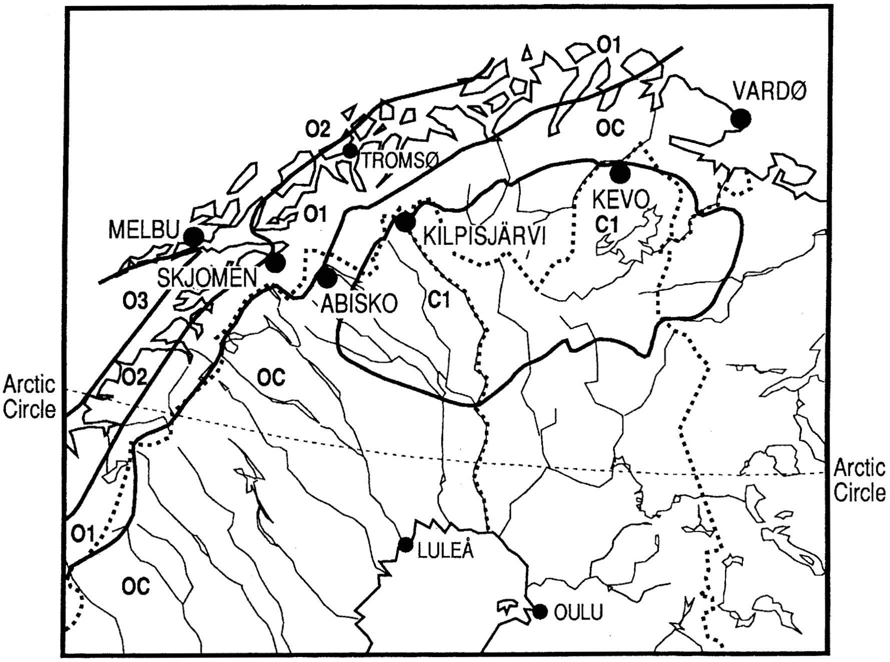


Fig. 1.2. Humidity sections in northern Fennoscandia, separated by thick solid lines. *O3* Most oceanic section, *C1* most continental section, *OC* in the middle of the scale from oceanic to continental regions. (Wielgolaski 2001)

weight of leaves, about twice as much as *Corylus avellana* and *Fagus silvatica,* and five times as much as spruce and pine (Pisek and Cartellieri 1939; Walter 1960).This, together with a preference for high air humidity for leaf bud break, may be important reasons for high cover of mountain birch in large areas of Fennoscandia. However, the variation in the species composition of different vegetation layers throughout the whole Fennoscandian region clearly reflects the changes in climate from south to north (temperature being most important in these zones, from the nemoral zone in the south to the northern boreal zone at higher elevations and in the north) and from coast to inland (humidity being most important in these so-called sections).

In the main mountain birch regions of northern Fennoscandia, such sections (Fig. 1.2) were given by Wielgolaski (2001), based on material presented by Moen and Odland (1993). Section O3 is the most oceanic section in Scandinavia and northern Finland, while C1 is the most continental one. More continental sections are missing in Fennoscandia. It is worth noting that the most humid sections are also missing, even along the coast of northernmost Norway (Fig. 1.2), mainly due to reduced precipitation in that part of Fennoscandia. Väre (2001) has classified the Nordic mountain birch woodland vegetation and Wehberg et al. have presented more details in plant sociological studies of northern Fennoscandia in Chapter 3.

In the most continental section (C1 in Fig. 1.2), lichens are more common than bryophytes in the bottom layer and *Vaccinium vitis-idaea* is very common in the field layer, maybe more so than *V. myrtillus*. The ground is normally oligotrophic and the biomass production low. Oceanic (O3–O2) and suboceanic (O2–O1) sections are dominated by mosses in the bottom layer and there are few lichens. Tall ferns are often found, and *Cornus suecica* is typical in the field layer of the O3–O1 sections (see also Chaps. 3 and 17). *V. myrtillus* is normally more common than *V. vitis-idaea*, while *Empetrum hermaphroditum* is abundant and in places totally dominant in these sections, and generally much taller than in the more continental sections. The tree layer of mountain birch in oceanic sections is also taller and much denser than in more continental sections (Hämet-Ahti 1963). Basal parts of the trees in C3–C1 are often very crooked because of snow slides on the often steep slopes and heavy snow cover of the oceanic sections. In some continental high altitude areas, a special, procumbent mountain birch type (var. *appressa*, see Chap. 7) is found. The nutrient conditions, particularly on the lower slopes of valleys and in calcareous ground in sections O3–O1, are often good and thus cause a rich field layer with many species. The production is high (Väre 2001) and the birches are commonly monocormic and may be up to 12 m tall.

1.4 Nutrient Conditions – Browsing

The shape of the mountain birch crown varies considerably (Fig. 1.3). Rapidly growing trees have a conical shape , which mainly indicates young, monocormic trees in eutrophic soil. A spherical crown indicates slower growth (Aradottir et al. 2001) on poorer soil, and is common in polycormic trees. Flat crowns are common at stagnant growth particularly in old trees and in oligotrophic heaths, where the growth is often shrubby and polycormic.

There seem to be several reasons for polycormic tree growth in mountain birch as discussed by Wielgolaski and Nilsen (2001; cf. also Chap. 7). Frequent introgression of *B. nana* genes into *B. pubescens* is an important factor for polycormy in the Nordic mountain birch, particularly in northern Fennoscandia (Vaarama and Valanne 1973; cf. Chap. 12), where such hybrids are common due to the two parent species flowering at nearly the same time in that area. Multi-stemmed birch trees may also be a result of sprouting after strong browsing by vertebrates (e.g. sheep and reindeer; cf. Chaps. 10 and 11; Haukioja and Heino 1974) or by invertebrates (see Chaps. 9 and 12; Haukioja 1991), typically in the ssp. *czerepanovii*. If monocormic trees, typically in the ssp. *pubescens*, survive browsing, including invertebrate attacks, they may not sprout with several saplings, but remain monocormic. This is, however, not always the case.

However, as mentioned earlier the nutrient conditions of the soil also seem to be important for the number of stems. As experimentally stated by Wielgolaski and Nilsen (2001), few stems or monocormic growth result from nutrient-rich soil. It might be speculated that if the reserves of minerals in soil or stored minerals and carbohydrates stored in roots and stems are limited, the lower part of the trees near these resources are favoured, which may cause dormant buds there to break and short shoots to be transformed to long shoots (cf. Haukioja et al. 1990). In richer soil, on the other hand, the compe-

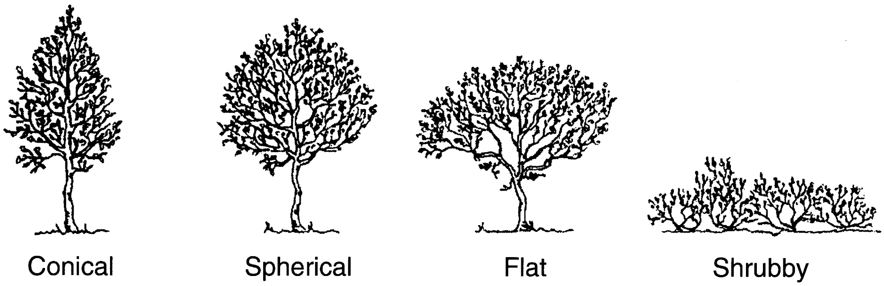


Fig. 1.3. Crown shape of mountain birch. From *left* to *right*: trees with good growth, particularly young trees in nutrient-rich soil under moist conditions to multi-stemmed low trees (normally less than 2 m) in poor soil and dry areas. The tallest conical trees with good growth are 10–12 m. (Aradottir et al. 2001)

tition for reserves is lower, which favours a normal apical dominance of the main stem, and the lower buds stay dormant or only develop short shoots. Midgley (1996) has hypothesized that resprouting in trees after a disturbance might be restricted to less productive areas. That fits well with the behaviour of the Nordic mountain birch. High soil moisture has also been suggested to favour monocormy (Verwijst 1988; Oksanen et al. 1995), and Kallio and Mäkinen (1978) suggested monocormic birch to be an adaptation to maritime climate. However, the influence of water on the number of stems was not confirmed in our experiments (Wielgolaski and Nilsen 2001), and can be seen as a result of intercorrelation with nutrients.

The geology of Fennoscandia is complex (e.g. Wielgolaski 1997), mainly with Precambrian, normally "acid" and poor gneisses and granites east of the Caledonids, the south–north mountain range all along Scandinavia, formed in the late Silurian to early Devonian time, some 400 million years ago. Because of a lack of lime-rich bedrocks, somewhat poorer metamorphic Cambrio-Silurian sediments, such as mica schists or phyllites, are generally the origin of the more nutrient-rich soil within the subalpine and alpine belts in Fennoscandia, with a pH of about 6 and a C/N ratio of about 15, compared to a pH often even below 4 and a C/N ratio up to 40–45 in raw humus layers in soil on hard, acid bedrocks (Wielgolaski 1975). In northern Fennoscandia podzolic profiles are well developed in the mountain birch forest (cf. Chap. 2), but the raw humus and bleaching layers become thinner towards the upper tree line (Kyllönen 1988). In the southern Norwegian mountains, a thin bleached soil layer is found up to an elevation of about 1300 m. In Iceland, most soils are classified as Andosols (Arnalds 1990), which are characteristic of areas with active volcanoes (Thorhallsdottir 1997). This soil is extremely susceptible to erosion (Arnalds et al. 1995).

Aradottir and Arnalds (2001) stressed that birch woodlands played a major role in conserving the fragile Icelandic soil before the settlement by man. Historically, rapid degradation and soil erosion were started by the settlers clearing the forests for farmsteads, fuel and charcoal. Even extensive clearing by fire took place, e.g. for preparing the areas for hayfields. In more recent times grazing by domestic herbivores, especially sheep, has had a very strong influence on the soil and vegetation. The birch woodland area of Iceland today is reported to be only about 3–4 % of the extent before settlement.

An experiment in a birch woodland in Iceland, protected from grazing for 70 years, clearly demonstrated the detrimental effect of sheep on rejuvenation of birch. After 5 years with the sheep, all birch seedlings and more than 75 % of the trees less than 1 m in height had been killed (Thorsteinsson 1986). When vegetation degradation reaches a critical point, massive soil erosion occurs, removing most of the fertile Andosol soil, which is replaced by infertile desert soil (Aradottir and Arnalds 2001).

Early in the 20th century, large-scale efforts to prevent erosion and reclaim severely degraded land began in Iceland. Today, around 15 % of the Icelandic birch woodland is fully protected from livestock grazing and over 10% is within national parks and reserves (Aradottir et al. 2001). Magnusson and Magnusson (2001) stressed that birch seedlings emerging adjacent to established willow plants appeared to be considerably larger than seedlings further away from the willows. They speculated about the possibility that nutrients and carbon were transferred to some extent via mycorrhizal links from the established willows to the birch seedlings, which can then benefit from the presence of mycorrhizal species existing on the willows. If this hypothesis is correct, the results may be used in future replacement of birch on degraded soil in Iceland.

Despite the often low content of nutrients in the soil at increased elevation, partly due to reduced liberation of nutrients at lower temperatures, there seems to be an increasing concentration of most minerals in plants with altitude (Körner 1989). In mountain birch this was observed in studies at different elevations in Swedish Lapland (Sveinbjörnsson et al. 1992). Weih and Karlsson (1999) suggested that potentially there is an adaptive influence to the variation in nutrient concentrations, particularly of nitrogen, in young birch plants from different altitudes. Minerals studied in birch forest plants at

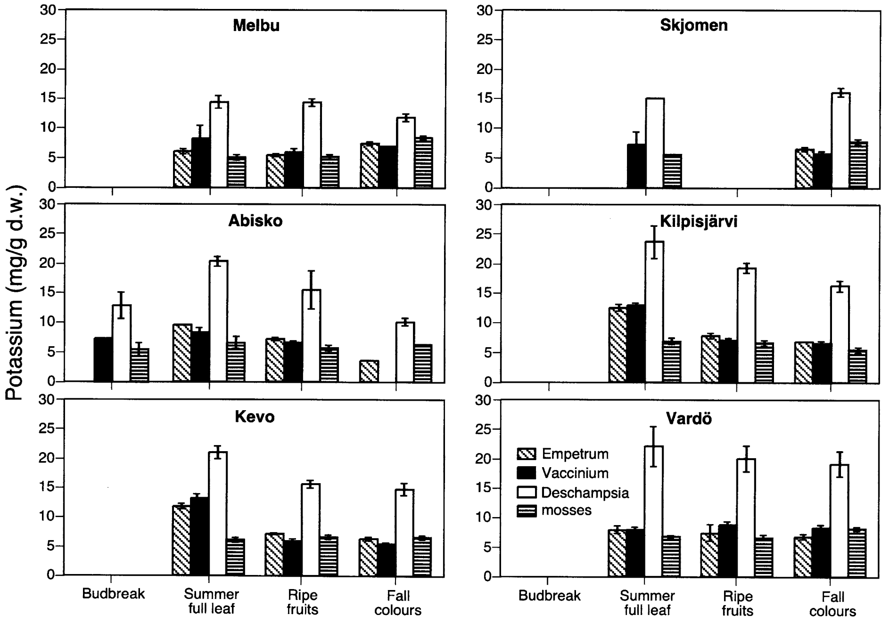


Fig. 1.4. Concentration of potassium at different phenophases of bilberries (blueberries) in new leaves and shoots of the understorey plants *Empetrum hermaphroditum*, *Vaccinium myrtillus*, *Deschampsia flexuosa* and the mosses *Hylocomium splendens* and *Pleurozium schreberi* in mountain birch ecosystems. (Partanen et al. 2001)

different sites in northern Fennoscandia, both in leaves and annual shoots of the trees and in various understorey plants, showed similar variations (Partanen et al. 2001). At specific phenophases before late autumn, the lowest concentrations of, e.g. potassium (Fig. 1.4), were found at the lowland sites Melbu and Skjomen, and the highest values at the mountainous Kilpisjärvi site, the coldest place studied (Table 1.1). Note that the highest content of K, and also of P and N, was found early in the growing season in green material. Such seasonal variation in the mineral concentration is also well known from the literature (e.g. Wielgolaski et al. 1975; Chapin et al. 1980; Körner 1989; Partanen et al. 2001). The concentration of organic material in mountain birch vegetation also varied of course with the phenophases, but, like the minerals, soluble sugar seemed to be highest in green compartments by the same phase at the coldest sites (Mäenpää et al. 2001; cf. Chap. 6). This may be seen as a reduced transfer to starch and lower transport in the plants at low temperatures.

References

Aas B, Faarlund T (2001) The Holocene history of the Nordic mountain birch belt. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 5–22

Ahti T, Hämet-Ahti L (1969) The homologies of the Fennoscandian mountain and coastal birch forests in Eurasia and North America. Vegetatio 19:208–219

Ahti T, Hämet-Ahti L, Jalas J (1968) Vegetation zones and their sections in northwestern Europe. Ann Bot Fenn 5:169–211

Alexandersson H, Karlström C, Larsson-McCann S (1991) Temperature and precipitation in Sweden. Reference normals. Meteorologi 81. SMHI, Norrköping, 87 pp

Aradottir AL, Arnalds O (2001) Ecosystem degradation and restoration of birch woodlands in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 293–306

Aradottir AL, Thorsteinsson I, Sigurdsson S (2001) Distribution and characteristics of birch woodlands in North Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 51–61

Arnalds O (1990) Characterization and erosion of Andisols in Iceland. PhD dissertation, Univ Texas A & M, College Station, TX, 179 pp

Arnalds O, Hallmark CT, Wilding LP (1995) Andisols from four different regions of Iceland. Soil Sci Soc Am J 59:161–169

Chapin FS III, Johnson DA, McKendrick JD (1980) Seasonal movements of nutrients in plants of different growth form in an Alaskan ecosystem: implications for herbivory. J Ecol 68:189–209

Fægri K (1950) Studies on the Pleistocene of western Norway IV. On the immigration of *Picea abies* (L.). Univ. Bergen Årbok, Naturvidensk Rekke 1949(1):1–52

Haapasaari M (1988) The oligotrophic heath vegetation of northern Fennoscandia and its zonation. Acta Bot Fenn 135:1–219

Hämet-Ahti L (1963) Zonation of the mountain birch forests in northernmost Fennoscandia. Ann Bot Soc 'Vanamo' 34(4):1–127

Hagman M (1971) On cross- and self-incompatibility shown by *Betula verrucosa* Ehrh. and *B. pubescens* Ehrh. Commun Inst For Fenn 73(6):1–125

Hanssen-Bauer I, Tveito OE, Førland EJ (2000) Temperature scenarios for Norway: Empirical downscaling from the ECHAM4/OPYC3 GSDIO integration. DNMI Rep 24:1–53

Hanssen-Bauer I, Tveito OE, Førland EJ (2001) Precipitation scenarios for Norway: empirical downscaling from the ECHAM4/OPYC3 GSDIO integration. DNMI Rep 10:1–39

Haukioja E (1991) The influence of grazing on the evolution, morphology and physiology of plants as modular organisms. Philos Trans R Soc Lond B 333:241–247

Haukioja E, Heino J (1974) Birch consumption by reindeer (*Rangifer tarandus*) in Finnish Lapland. Rep Kevo Subarctic Res Stn 11:22–25

Haukioja E, Ruohomäki K, Senn J, Suomela J, Walls M (1990) Consequences of herbivory in the mountain birch (*Betula pubescens* ssp. *tortuosa*): importance of the functional organization of the tree. Oecologia 82:238–247

Helland A (1912) Trægrændser og sommervarmen (in Norwegian). Tidsskr Skogbr 20:131–146, 169–175, 303–313

Høgda KA, Karlsen SR, Solheim I (2001) Climatic change impact on growing season in Fennoscandia studied by a time series of NOAA AVHRR NDVI data. Proc IGARSS 2001, Sydney, Australia, ISBN 0–7803–3:1–3

Hofgaard A (1997) Inter-relationships between treeline position, species diversity, land use and climate change in the central Scandes Mountains of Norway. Global Ecol Biogeogr Lett 6:419–429

Järvinen A (1987) Basic climatological data on the Kilpisjärvi area, NW Finnish Lapland. Kilpisjärvi Notes 10:1–16

Kärenlampi L (1972) Comparisons between the microclimates of the Kevo ecosystem study sites and the Kevo Meteorological Station. Rep Kevo Subarctic Res Stn 9:50–65

Kallio P, Mäkinen Y (1978) Vascular flora of Inari Lapland. 4. Betulaceae. Rep Kevo Subarctic Res Stn 14:38–63

Körner C (1989) The nutritional status of plants from high altitudes. A worldwide comparison. Oecologia 81:379–381

Kullman L (2000) Tree-limit rise and recent warming: a geoecological case study from the Swedish Scandes. Norsk Geogr Tidsskr 54:49–59

Kullman L (2002) Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. J Ecol 90:68–77

Kullman L, Kjällgren L (2000) A coherent tree-limit chronology (*Pinus sylvestris* L.) for the Swedish Scandes: Aspects of paleoclimate and "recent warming", based on megafossil evidence. Arct Antarct Alpine Res 32:419–428

Laitakari E (1935) The root system of birch (*Betula verrucosa* and *odorata*). Summary. Acta Fort Fenn 41:171–216

Lippestad H (ed) (2003) Normaler, temperatur og nedbør (observasjoner, fylke, normaler, kommune). http://met.no/observasjoner/index.html (in Norwegian)

Kyllönen H (1988) Alpine and subalpine vegetation at Kilpijärvi, Finnish Lapland: distribution of biomass and net production and annual variation of biomass. Acta Univ Oul A 202:1–78

Mäenpää E, Skre O, Malila E, Partanen R, Wielgolaski FE, Laine K (2001) Carbon economy in birch-dominated ecosystem species in northern Fennoscandia. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 93–114

Magnusson SH, Magnusson B (2001) Effect of enhancement of willow (*Salix* spp. on establishment of birch (*Betula pubescens*) on eroded soils in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 317–329

Midgley JJ (1996) Why the world's vegetation is not dominated by resprouting plants; because resprouters are shorter than reseeders. Ecography 19:92–95

Moe D, Indrelid S, Kjos-Hanssen O (1978) A study of environment and early man in the south Norwegian highlands. Norw Arch Rev 11:73–83

Moen A (1999) National atlas of Norway: vegetation. Norw Mapping Authority, Hönefoss, 200 pp

Moen A, Odland A (1993) Vegetasjonsseksjoner i Norge (in Norwegian). Univ Trondh VitenMus Rapp Bot Ser 2:37–53

Nilsen J, Wielgolaski FE (2001) Effects of fertilization and watering on morphology in young mountain birch plants of different provenances – a pilot study. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 71–76

Odland A (1996) Differences in the vertical distribution pattern of *Betula pubescens* in Norway and its ecological significance. In: Frenzel B (ed) Holocene treeline oscillations, dendrochronology and paleoclimate. Fischer, Stuttgart, pp 43–59

Oksanen L (1995) The isolated occurrences of spruce *Picea abies*, in northernmost Fennoscandia in relation to the enigma of continental mountain birch forests. Acta Bot Fenn 153:81–92

Oksanen L, Moen J, Helle T (1995) Timberline patterns in northernmost Fennoscandia. Relative importance of climate and grazing. Acta Bot Fenn 153:93–105

Partanen R, Wielgolaski FE, Malila E, Mäenpää E, Laine K (2001) Inorganic nutrient content in plant species of mountain birch-dominated ecosystem in northern Fennoscandia. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 155–171

Pisek A, Cartellieri E (1939) Zur Kenntnis des Wasserhaushaltes der Pflanzen. IV. Bäume und Sträucher. J Wiss Bot 88:22–68

Sonesson M, Hoogesteger J (1983) Recent tree-line dynamics (*Betula pubescens* Ehrh. spp. *tortuosa* (Ledeb.) Nyman) in northern Sweden. Nordicana 47:47–54

Sveinbjörnsson B, Nordell O, Kauhanen H (1992) Nutrient relations of mountain birch growth at and below the elevational tree-line in Swedish Lapland. Funct Ecol 6:213–220

Thorhallsdottir TE (1997) Tundra ecosystems of Iceland. In: Wielgolaski FE (ed) Polar and alpine tundra. Elsevier, Amsterdam, pp 85–96

Thórsson AT, Salmela E, Anamthawat-Jónsson K (2001) Morphological, cytogenetic and molecular evidence for introgressive hybridization in birch. J Hered 92:404–408

Thorsteinsson I (1986) The effect of grazing on stability and development of northern rangelands: A case study of Iceland. In: Gudmundsson O (ed) Grazing research at northern latitudes. Plenum Press, New York, pp 37–43

Vaarama A, Valanne T (1973) On the taxonomy, biology and origin of *Betula tortuosa* Ledeb. Rep Kevo Subarctic Res Stn 10:70–84

Väre H (2001) Mountain birch taxonomy and floristics of mountain birch woodlands. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 35–46

Verwijst T (1988) Environmental correlates of multiple stem formation in *Betula pubescens* ssp. *tortuosa* (*B. tortuosa*). Vegetatio 76:29–36

Wahlenberg G (1812) Flora Lapponica. In Taberna Libraria Scholae Realis, Berolini, 550 pp

Walter H (1960) Grundlagen der Pflanzenverbreitung. I. Teil. Standortslehre. Ulmer, Stuttgart, 566 pp

Walter H (1974) Die Vegetation Osteuropas, Nord- und Zentralasiens. Fischer, Stuttgart, 452 pp

Weih M, Karlsson PS (1999) Growth and nitrogen economy of mountain birch seedlings from different altitudes. Oecologia 119:16–23

Wielgolaski FE (1975) Functioning of Fennoscandian tundra ecosystems. In: Wielgolaski FE (ed) Fennoscandian tundra ecosystems, part 2. Animals and systems analysis. Springer, Berlin Heidelberg New York, pp 300–326

Wielgolaski FE (1997) Fennoscandian tundra. In: Wielgolaski FE (ed) Polar and alpine tundra. Elsevier, Amsterdam, pp 27–83

Wielgolaski FE (1999) Starting dates and basic temperatures in phenological observations of plants. Int J Biometeorol 42:158–168

Wielgolaski FE (2001) Vegetation sections in northern Fennoscandian mountain birch forests. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 23–33

Wielgolaski FE (2002) Nordic mountain birch forests. In: Kankaanpää S, Müller-Wille L, Susiluoto P, Sutinen M-L (eds) Northern timberline forests: Environmental and socio-economic issues and concerns. Finn For Res Inst Res Pap 862:76–90

Wielgolaski FE (2003) Climatic factors governing plant phenological phases along a Norwegian fjord. Int J Biometeorol 47:213–220

Wielgolaski FE, Nilsen J (2001) Coppicing and growth of various provenances of mountain birch in relation to nutrients and water. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 77–92

Wielgolaski FE, Kjelvik S, Kallio P (1975) Mineral content of tundra and forest tundra plants in Fennoscandia. In: Wielgolaski FE (ed) Fennoscandian tundra ecosystems, part 1. Plants and microorganisms. Springer, Berlin Heidelberg New York, pp 316–332

2 Soils and Nutrients in Northern Mountain Birch Forests: A Case Study from Finnmarksvidda, Northern Norway

K.-D. Meier, D. Thannheiser, J. Wehberg, and V. Eisenmann

2.1 Introduction

Although birch forests cover large areas of northern Fennoscandia, with the mountain birch *Betula pubescens* ssp. *czerepanovii* often forming the altitudinal and arctic forest line, very little is known about the soils typical for these areas. This is a great difference from the boreal coniferous region farther to the south and the arctic–alpine belt of the Caledonian mountain range, where quite a few studies dealing with soils in different ways have been carried out in the past decades (e.g. Jauhiainen 1969, 1970; Ellis 1979, 1980, 1983, 1985; Kühn 1983; Breburda 1987; Meyer et al. 1988; Venzke 1990; Darmody et al. 2000). There are only a few publications on Quaternary deposits and soils in the northern Fennoscandian mountain birch forests (e.g. Haapasaari 1988; Stützer 1995), the most comprehensive describing soil types and their distribution near the forest line some kilometres to the south of Alta, Finnmark (Mosimann 1981). More recent publications concentrate on special aspects of soil formation within the birch forests, such as the influence of long-lasting frozen ground and permafrost (e.g. Meier 1985, 1987, 1991, 1996). With this background, soils were investigated in more detail during the summers of 2001 and 2002 as a case study in connection with the EU project HIBECO (Human Impact on Mountain Birch Ecosystems) in the gently undulating plateau landscape of the Finnmarksvidda between the Alta river power plant in the north and the Finnish-Norwegian national border in the south (see details given on the attached CD, and Chap. 2).

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

2.2 Study Area

The area of the case study in northern Fennoscandia is part of the Alta-Kautokeino river drainage basin north of the Arctic Circle (see CD, Fig. 2A). The Arctic forest line separating the boreal vegetation zone from the Arctic vegetation zone runs farther to the north describing a large curve from North Cape, crossing the outer reaches of the Varanger peninsula to the island of Vardø in the northeast (Moen 1999). Within the study area, the forest line is an altitudinal limit, separating the boreal vegetation belt from the alpine vegetation belt above. Both the latitudinal and the altitudinal forest line reflect the decrease in summer temperature, limiting the presence of birch trees (cf. Chap. 1). About three fifths of the study area is covered with birch forest, representing the northern boreal vegetation zone. With increasing altitude the birch forests are replaced by stunted shrubs, heath and meadow associations belonging to the low alpine vegetation belt. The forest line ranges from ca. 400 m a.s.l. at the fjord heads in the north to ca. 500 m a.s.l. on the inland plateau, which is characterized by a more continental climate.

The main physio-geographic pre-conditions of the case study area, which control the soil-forming processes at a different intensity in a very complex way, can be characterized as follows:

The macro-relief is predominated by vast, smooth and gently undulating plateaus of moderate altitudes (300–500 m a.s.l.), which are overtopped by several mountain chains reaching absolute heights of 600–650 m a.s.l. In the northern part, this plateau landscape is cut by the valley of the Alta river, forming steep cliffs and talus slopes. Most of the tributary valleys follow geological fault lines. In the south, near the Finnish border, the extensive plateaus form a typical peneplain which is criss-crossed by some flat, broad river valleys draining into the Kautokeino river. A great many of the topographical depressions contain lakes and bogs.

Concerning the bedrock geology, the case study area is situated near the edge of the Scandinavian Caledonian mountain chain (see CD, Fig. 2B). The northernmost part is built up by metasandstones, quartzites, conglomerates, amphibolites and mica schists of the Caledonian Kalak nappe complex, underlain by conglomerates, shales and sandstones of the Dividal Group. However, by far the largest part of the area is located south of the thrust front, thus belonging to the Fennoscandian Shield, mainly consisting of mica schists, greywackes, phyllites, amphibolites and quartzites as well as plutonic and intrusive rocks such as granites, granodiorites, gneisses and dolerites (Siedlecka and Roberts 1996).

The pre-Quaternary bedrock is nearly continuously covered by Quaternary deposits (see CD, Fig. 2C). Bedrock outcrops are restricted to river channels and some scattered mountain tops. Pleistocene ice sheets covered the whole research area at different times, the last during the Late Weichselian glaciation leaving behind a thick and continuous cover of glacial drift material (Olsen et al. 1996). The silty or sandy till beds contain short-transported stones and blocks. Deglaciation took place between 10.0 ka B.P. (in the north, Altafjord) and 9.2 ka B.P. (in the south, Norwegian-Finnish border). Fragments of a large esker system, composed of sand and gravel, are evidence of a subglacial drainage in a northern direction. The eskers and similar forms farther to the east are covered locally by eolian sand deposits; the sand originates from dry river and lake bottoms in front of the retreating ice sheet. After deglaciation and establishment of the vegetation cover, large and deep peat bogs were formed in numerous topographical depressions, favoured by the dense bedrock in the ground and the cold climate inhibiting decomposition of plants.

Many topographical depressions in the continental parts of northern Fennoscandia are occupied by peat bogs, many of which contain palsas indicative of recent permafrost. More than 300 palsa bogs were mapped; the vast majority has developed in the southern, more continental part of the study area, mostly below the forest line (see CD, Fig. 2D). North of the village of Máze the number of peat bogs deep enough for the formation of palsas and permafrost decreases. However, permafrost was also found in mineral soils outside the palsa bogs, especially in fine-grained sediments at cold-exposed, wind-swept locations, characterized by a thin snow cover in winter (Meier 1987). The clearly negative mean annual air temperatures, the high mean annual number of negative degree days (freezing indices) and the negative mean annual warming balances are reasons that the inner parts of northern Fennoscandia belong to the zone of discontinuous permafrost, though the permafrost distribution is not known in detail as yet (Meier 1991, 1996, 1997). The "warm" and wet climate of the 1990s is reflected in most of the palsa bogs by a very small number of young embryonic palsas. Whether the decay of old palsas is accelerated as well is hard to prove as the palsas are characterized by a cyclic development. At some localities ice-rich palsa plateaus, covered by birch forests, degrade quite fast, leaving behind an impressive thermokarst landscape with dying birch trees.

2.3 Soil Classification

Dependent on the variable physio-geographic pre-conditions, such as topography, aspect, bedrock, Quaternary deposits, local climate, vegetation, moisture and time, quite different soil types have developed, including both subtypes and variants and transitions to other soil types, thus making the taxonomic classification in the field sometimes complicated. The soils were examined and described by standard techniques (Bodenkundliche Kartieranleitung 1994); soil samples were collected by horizon. The case study sites were chosen to give a representative selection of the variability in topography, geomorphology, elevation, aspect and climate. However, most of the sites were initially selected on the basis of the vegetation communities, because the working hypothesis suggested that they were related.

Among the soils found in the case study area, podzols, as the zonal soil type in the northern boreal vegetation region, are predominant (Fig. 2.1). According to Jauhiainen (1969), humus-podzols and iron-humus-podzols should be most widespread. Still, the authors' own fieldwork shows that iron-podzols and iron-humus-podzols prevail, whereas typical humus-podzols are rare. The distinction between iron-podzols and iron-humus-podzols turned out to be difficult in the field, as the podzolization was often quite weak (colour of the B-horizon not intense). Moreover, iron-humus-podzols with a two-layered illuvial horizon (Bh-Bs profile), typical of many areas in central Europe, are quite exceptional in the study area. The enrichment of iron and humus colloids in the B-horizon seems to be masked by each other (Mosimann 1981). A typical feature of many podzols (and other soil types) is a relatively thick organic layer as a consequence of the slow humification and mineralization of the plants caused by the severe climatic conditions, especially the long and

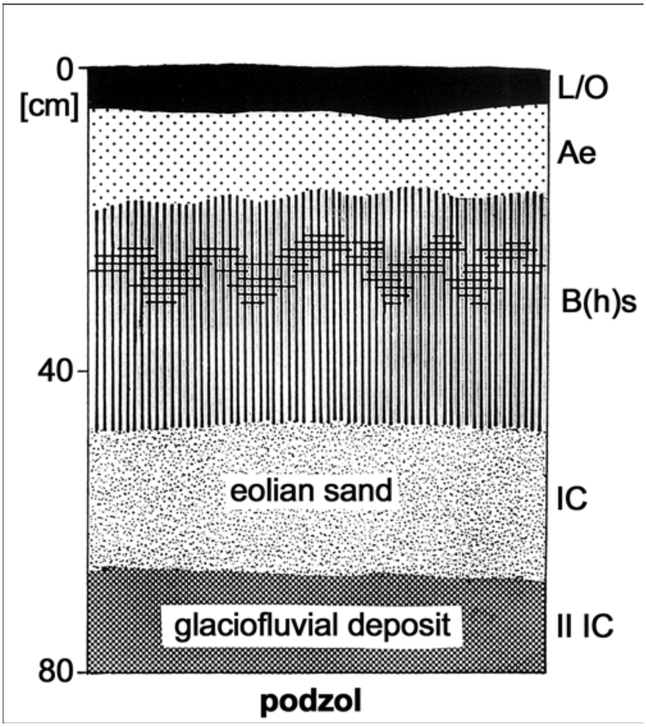


Fig. 2.1. Typical podzol profile in the Máze area, Finnmark county, Norway

cold winters. The formation of humus manifested as an Ah-horizon is restricted. In many soil profiles, the Ah-horizon is totally missing. In such cases, there are no humus colloids that can be washed down; a Bh-horizon cannot form. This may explain the small number of typical humus-podzols and iron-humus-podzols observed in the field.

In this study, normal podzols are characterized by an Ae-horizon and a Bs/Bsh/Bh-horizon exceeding a thickness of 30 cm. In the case of nanopodzols (dwarf podzols), the total thickness of the two horizons is 15–30 cm. If the thickness is <15 cm, the soil is classified as podzol–regosol. Cryoturbated horizons can render this classification difficult from place to place. In addition to typical podzols and their subtypes, transitions to other soil types, such as gleys, are found. Along rivers and lake shores, gley soils are formed under the influence of a periodically changing groundwater level. Where impermeable bedrock or till is overlain by water-saturated mineral soil, pseudogley profiles have developed. At the bottom of the valleys there are widespread alluvial plain soils which can be classified as rambla (alluvial plain syrosem in loose deposits), paternia (alluvial plain regosol) and vega (brown alluvial plain soil). On the slopes podzols are predominant, but colluvisols and rankers are found as well. Though permafrost exists locally, typical soil types connected with perennially frozen ground (gelisols) were not observed outside the palsa bogs, maybe because the active layer was too thick and the permafrost table more than 1.3 m below the surface. Nevertheless, it is striking that nearly all these soil profiles showed heavily cryoturbated horizons near the surface, especially well documented in frost-susceptible, fine-grained sediments.

2.4 Soil Distribution

The development of a soil profile could only start after a vegetation cover had been established. After the deglaciation a sparse vegetation cover, low temperatures and cryoturbation processes affecting the sediments inhibited the soil profile development. Taking all this into account, the land surface age decreases only by about 800 years from the northern to the southern Finnmarksvidda – not very much for a distance of 120 km. Thus, the time to develop soil profiles was quite long in the whole case study area; on the time scale all areas have similar pre-conditions for pedogenesis.

A comparison of the soil types observed in the northern and in the southern halves of the case study area shows the largest variety in the north, caused by more variable relief, slope, aspect, bedrock and vegetation (see CD, Table 2A). The vast undulating plateaus of both areas, covered by sandy glacial till and lichen-rich *Empetrum* birch forests (*Empetro-Betuletum pubescentis*, see Chap. 3), are dominated by nanopodzols which are often strongly cryoturbated, especially at localities near the forest line. The predominance of nanopodzols is quite surprising, as similar sites near the coast of northernmost Norway are often characterized by thicker soil profiles forming typical podzols. There nanopodzols are mainly found above the forest line. On the till plateaus of the Finnmarksvidda well-developed podzols seem to be rare. However, they are widespread in permeable eolian sands, which favour the vertical percolation of water and colloids. The best-developed iron-podzols and iron-humus-podzols with strongly hardened illuvial horizons reach profile depths up to 1 m. More wind- and cold-exposed places within and above the birch forests are characterized by podzol regosols or syrosems in loose deposits. The reasons for an intensified podzolization in the coastal area compared with the inland plateau are not known. The higher precipitation sums at the coast may be one reason; the shorter period with frozen ground another one. Whether the earlier deglaciation of the coastal region also plays a certain role cannot be decided as yet. Though very widespread in the gently rolling plateau landscape of the Finnmarksvidda, bog soils were only studied at several selected sites where birch forests are bounded by peat bogs. The higher number of peat bogs in the southern half of the study area compared to the northern half can be explained by the predominant bas relief with many topographical depressions, underlain by dense impermeable bedrock. Peat formation is favoured by relatively warm summers with a high biomass production and a slow decomposition of the organic material, caused by low temperatures during the long winter. Drillings and excavations (near Kautokeino) revealed that the peat layers can be some metres thick, locally up to 5 m. If the peat thickness exceeds 70–80 cm (coast: 50–60 cm), permafrost may occur (Meier 1985, 1987, 1991, 1996). During summer, the dry porous insulating peat cover prevents the frozen ground from thawing. The thickness of the active layer varies from place to place and may change from year to year. In a palsa near Máze (Stuoroaivi, 450 m a.s.l.) the permafrost table was found 50–70 cm below the peat surface (2001, 2002). In many cases, the mineral soil at the bottom of the peat bog is frozen too.

A vertical differentiation of the soils, controlled by climate and vegetation, can be observed both in the northern and in the southern half of the Finnmarksvidda. It is more striking in the north than in the south, and caused by a steeper relief. Near the Finnish-Norwegian border, the upper courses of the river valleys are only moderately cut into the plateau landscape. North of Máze the steep-sided Alta river valley cuts deeply into the plateau, the relief energy reaching about 500 m. In comparison with the inland plateaus, the forest limit is “sharp-lined” on many slopes. However, test pits dug into glacial till and glacio-fluvial deposits below and above the forest line indicated only a gradual transition of the soils. On relatively wet slopes, 100–150 m below the forest line, podzols and colluvisols, covered by moss-rich *Myrtillus* birch forests (*Vaccinio myrtilli-Betuletum*, see Chap. 3), were found. Upslope 50–80 m, the horizons were thinner and cryoturbated in some cases, forming typical nanopodzols. At the forest line and on the upper slopes, covered by dwarf shrubs, nanopodzols prevail. On wind-swept, frost-exposed plateaus, where the vegetation cover is scattered, podzol regosols and syrosems predominate. Podzol regosols are typical for places where the podzolization processes are delayed by climatic and/or edaphic drawbacks. On the slopes, they often characterize deposits affected by gelifluction and abluation. On the plateaus cryoturbation and deflation processes are the most disturbing factors. Moreover, the production of humus and aggressive acids, which are able to mobilize Fe and Al, is restrained at places with open vegetation. High wind speeds may increase the evaporation and, as a consequence, retard the vertical percolation of soil water, resulting in a low podzolization rate (Mosimann 1981). Syrosems, as an initial stage of pedogenesis, are observed in loose deposits and bedrock above the forest line. In the forest belt they are rare. Bedrock syrosems occur on fresh weathering scars on bedrock drumlins, whale back forms and along the steep canyon walls of the Alta river valley. As the position of the forest line is not stable in time, but may have oscillated in the past, the soil profiles close to it may have developed under quite different pre-conditions concerning the vegetation cover.

The rough zonal and altitudinal soil pattern, directed by the macro-climate and the vegetation belts, is strongly modified by variable local conditions such as bedrock, Pleistocene and Postglacial deposits, moisture, slope gradient, vegetation type and density. The bedrock, through its acidity and the characteristics of its weathering products, influences the soil development. The properties of the substratum result from the characteristics of the bedrock ("lithologic" pre-conditions) and the characteristics of the unconsolidated surficial deposits ("edaphic" pre-conditions). Frost weathering of the most widespread bedrock, quartzite, sandstone, conglomerate and granite, mainly supplies sandy detritus (pH 3–6). Amphibolites, phyllites and schists are less resistant, forming flattened weathering products. The occurrence of limestone, dolomite, marble and mafic rocks seems to be quite restricted. The properties of the glacial deposits reflect the characteristics of the local bedrock, since the material is mostly transported short distances (<10 km). In addition to weathering products of the local bedrock and glacial till, there are glacio-fluvial deposits forming eskers, kames, river terraces and outwash plains. The material consists mainly of sand and gravel and includes clay and silt beds. The Postglacial rivers accumulated fluvial deposits of silt, sand and gravel in their lower courses, forming alluvial plains which are still flooded in parts during the snow melt period in May. The slope deposits often contain material of different origins, such as weathering products of the local bedrock, glacial till and eolian sand, locally dislocated and mixed by gelifluction processes. On river terraces and esker ridges eolian sand deposits are abundant. In many topographical depressions – and even on gentle slopes – the minerogenic deposits are covered by organic layers, giving rise to bog soils and, if the thickness is sufficient, to permafrost or at least to semi-perennial frost lenses in the ground.

The "relief" factor controls the soil development in different ways, directly and indirectly. The macro-relief has an influence on the climate. Normally the air temperature decreases with altitude. However, in some trough-like parts of the valleys (e.g. the Máze valley), temperature inversions are frequent, especially in winter. In summer and autumn, the valley has more fog (and moisture) than the nearby plateaus. The steep west-facing slopes and mountain walls are characterized by higher amounts of precipitation than the lower east-facing slopes. On the other hand, east-facing slopes favour the accumulation of snow in the study area (lee effect). Thick snow banks can last for a long time, supplying water to the surroundings and thus controlling the ground frost regime and the growth of plants. On the gently undulating plateaus and in the flat valley bottoms, where mass movements are missing, undisturbed soil profiles can develop if cryoturbation processes, deflation (plateaus) and fluvial sedimentation (alluvial plains) are absent. On the slopes gelifluction and erosional processes may influence the development of soil profiles from time to time. If the soil is water-saturated, as at the end of the snow melt period, a slope gradient of 2–3° can be enough to initiate gelifluction processes. At gradients >30° abluation and sliding processes predominate. Typical sites with unstable soil conditions were found downslope from springs. The water supply not only enhances slope morphodynamics, but also controls the plant life. Both vegetation cover and moisture conditions are strongly influenced by slope gradient and relief.

Moisture is a controlling factor for soil development. It determines which soil type can develop and at what rate. From all soils studied on the Finnmarksvidda, around 80 % are podzols and nanopodzols. Moisture can be present as soil water content, percolating water, slope water that is supplied episodically or periodically, and groundwater. The intensity of the water supply depends on topography, the properties of the substratum and the thickness of the loose deposits (Mosimann 1981).

The complex relations between the different factors controlling the distribution of the soil types in the case study area are exemplified in a hypsometrical profile across the Kautokeino river valley at Máze (Fig. 2.2a). It shows the soil types and related forest types in a 3.5 km long strip of terrain covering an altitudinal range of 178 m between the Kautokeinoelv and the summit of Girkucåkka. It is representative for the northern part of the study area, including a plateau, valley slopes with different gradients and aspects, an alluvial plain and a relatively steep-sided mountain ridge reaching just above the forest line.

The valley follows a structural fault line running SW–NE. The bedrock consists of quartzite, locally with layers of conglomerate, marble, quartz-albite felsite, amphibolite and mica schist. On the western plateau it is covered by glacial till and peat deposits. The valley slopes are characterized by debris

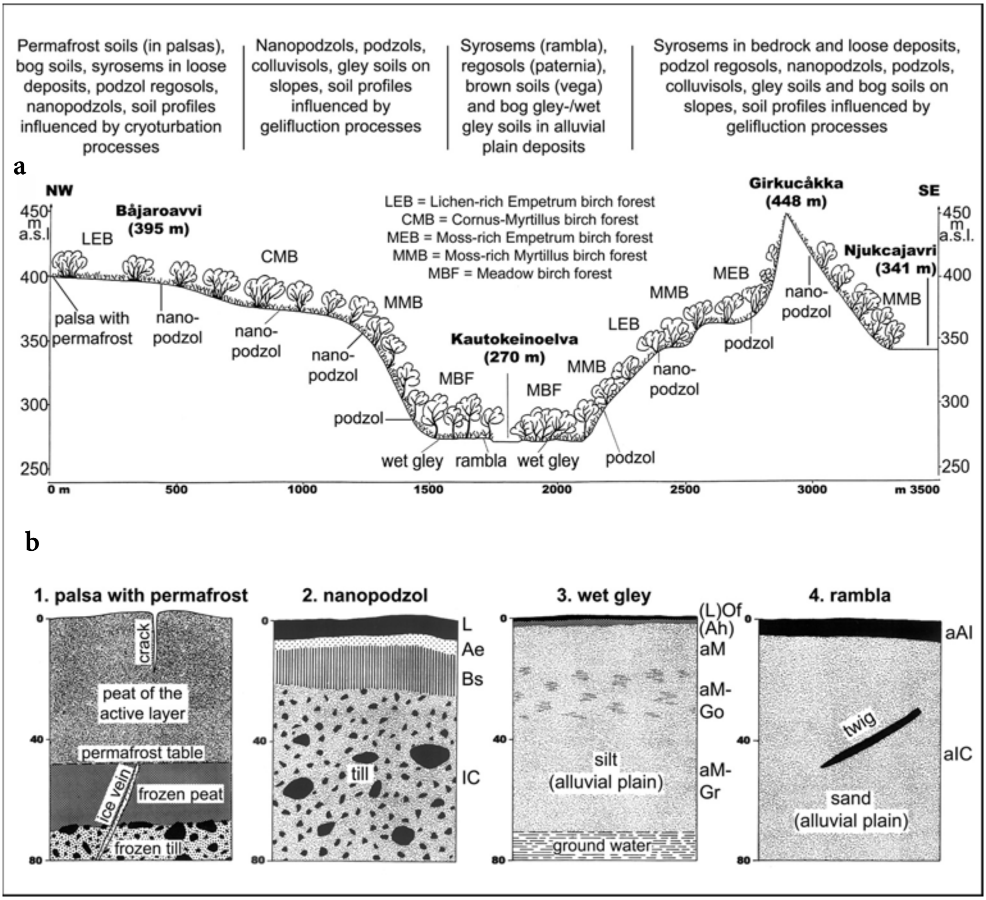


Fig. 2.2. **a** Hypsometrical profile across the Kautokeino River valley at Máze. **b** Soil profiles: *1* palsa with permafrost, *2* nanopodzol, *3* wet gley, *4* rambla

derived from the local bedrock, glacial till, glacio-fluvial and eolian sand, as well as bedrock outcrops. Because of gelifluction, the layers are often heavily mixed. The valley bottom is filled with alluvial sand and silt deposits of unknown thickness, forming an alluvial plain, which is periodically flooded during the snow melt in May.

Farther to the NW there are some small palsa bogs with permafrost lenses (Fig. 2.2 a, Fig. 2.2 b1–2). On the wind- and frost-exposed plateau, nanopodzols, which are often cryoturbated, prevail. The most exposed sites are characterized by podzol regosols and syrosems in glacial till. The upper, more gentle slopes of the escarpment to the SE have nanopodzols as the predominant soil type. The steeper slopes are characterized by nanopodzols on the upper slope segments, podzols, colluvisols and gley soils in wet hollows and gullies. Many soil profiles are influenced by gelifluction processes. Where eolian sand deposits occur on the lower slopes, iron-podzols and iron-humus-podzols have developed. On the alluvial plain soils have formed under the influence of groundwater. The changing groundwater level is controlled by the river. During the snowmelt period, parts of the alluvial plain are flooded and fine-grained sediments such as sand and silt accumulate, forming new sediment layers upon the old land surface. According to the water supply and the time available for soil-forming processes, different soil types including initial stages are found, like syrosems (rambla), regosols (paternia), brown soils (vega) and bog/wet gley soils (Fig. 2.2 a,Fig. 2.2 b 3–4). On the NW-facing slopes of the valley, gley soils and bog soils (in slope hollows) are predominant in addition to podzols and colluvisols. On the SE-facing slopes podzols and nanopodzols prevail, often affected by cryoturbation processes. The summit of Girkucåkka is characterized by dwarf shrubs and stunted birch trees (Fig. 2.2a). Bedrock outcrops indicate that bedrock is close to the surface at many places. Consequently, only thin nanopodzols and podzol regosols occur, complemented by syrosems in loose deposits and bedrock. It is striking that most of the soil profiles on the transect show a comparatively thick organic layer.

2.5 Soil Properties

The soil properties were studied in detail along the hypsometrical profile across the river valley at Máze. The laboratory work included, among other things, determination of the colours (Munsell colour chart) and reactions (pH), particle size distribution, organic carbon contents, C/N ratios and exchange capacity of cations (CECs).

Bedding, sorting and texture of the soils are pre-conditioned by the origin of the substratum. The nonsorted glacial till covering most slopes and plateaus is locally rich in gravel-sized particles. The fine soil is predominated by sand and silt, while the clay portion reaches 6 % at best. The high silt content in some soil samples, ranging between 70 and 80 %, is striking. It makes the soil very frost-susceptible; cryoturbation processes (on plateaus) and gelifluction processes (on slopes) are favoured. The fluvial and glacio-fluvial deposits of the alluvial plain and the lower slopes are mostly well-sorted. The particle size distribution changes from place to place, depending on the conditions during sedimentation. Most of the soil profiles are dominated by thick sand and silt beds underlain by gravel deposits. In the alluvial plain on the valley bottom the silt content may exceed 85 % of the fine soil, though, in general, the sand fraction prevails. The clay content ranges from 2 to 6 %. The eolian sand deposits near the river channel show a homogeneous grain size distribution; 95–100 % of the soil belongs to the sand fraction, in which fine sand and middle sand clearly dominate. The extremely low clay content in all the soil samples indicates that production of this size material by weathering processes is minimal in the Máze area. In most soil profiles pedogenesis does not exceed 50 cm in depth. Exceptions are the eolian sand deposits, in which the texture favours the vertical percolation of water and the development of deeper soil profiles (up to 1 m).

The majority of the soil profiles is characterized by comparatively thick organic layers. They can represent a significant water reservoir after the snowmelt period. In most cases, they are developed as raw humus with an organic carbon content >40 % and a C/N ratio >20 (see also Wielgolaski 1975). Topsoils rich in humus are lacking in most places. The eluvial horizons are thin (nanopodzols), containing 0.3–1.1 % of organic carbon. A slightly higher content of organic carbon is found in moss-rich *Myrtillus* birch forests and in meadow birch forests covering the alluvial plain. Sites characterized by organic carbon <0.5 % are dominated by lichen-rich birch forests, in which the moisture content of the soil is low. Locally, the carbon content of the topsoils can be exceeded by the respective values of the illuvial horizons. The C/N ratios of the topsoils do not show any quantitative relation to the vegetation cover, indicating a very slow decomposition of the organic material resulting from restricted biological activity.

All sites are characterized by a significant, but shallow, acidification of the soils (Fig. 2.3). The topsoils of the podzols and nanopodzols are strongly

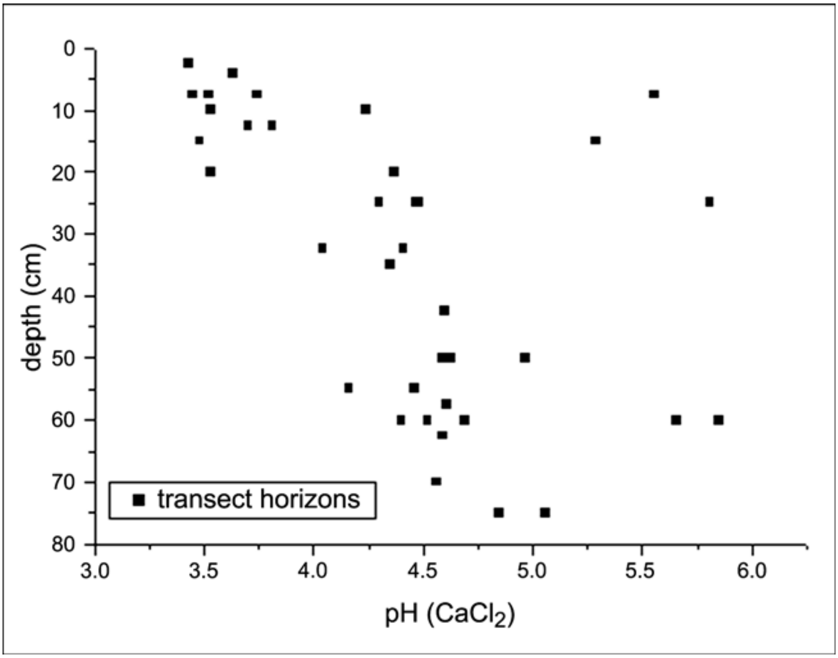


Fig. 2.3. pH values in relation to soil depth in the Máze area

acidic. The pH values of the eluvial horizons range from 3.5 to 3.8. The transition to the B-horizons is marked by a notable pH increase by 0.5–1.0 pH units. Soils on plains show a steady increase in pH values with depth, indicating long-lasting stability. On steeper slopes discontinuities in pH increase with depth may occur, mostly resulting from mass movements affecting the surficial deposits. The wet gley soils of the alluvial plain, covered by meadow birch forests, can be classified as moderately acidic. The pH value (5.6) is much higher than on the slopes and plateaus. However, a pH increase with depth is missing. This can be explained by unstable soil conditions caused by periodical floods and sedimentation during the snowmelt.

The investigated eluvial horizons show base saturations of 22–74 %. The majority of the sites are moderately rich in base cations. The most important ion bound to exchange sites is calcium, which shows a close relation to magnesium (Fig. 2.4). The soils are mainly buffered by aluminium oxides. This means that the soil solution and the exchange sites should contain aluminium. The effective cation exchange capacity (CEC) of the soils is quite low, ranging from 7 to 24 mmol/kg. Only at valley sites (alluvial plain) do exchange capacities up to 48 mmol/kg occur. This relatively high exchange capacity is only in part caused by the silicate and organic material. A comparison with sites of similar particle size distribution and locally even higher humus content clearly indicates that crystalline iron oxides can provide up to 50 % of the exchange sites. These iron oxides are visible as rust stained patches in the soil

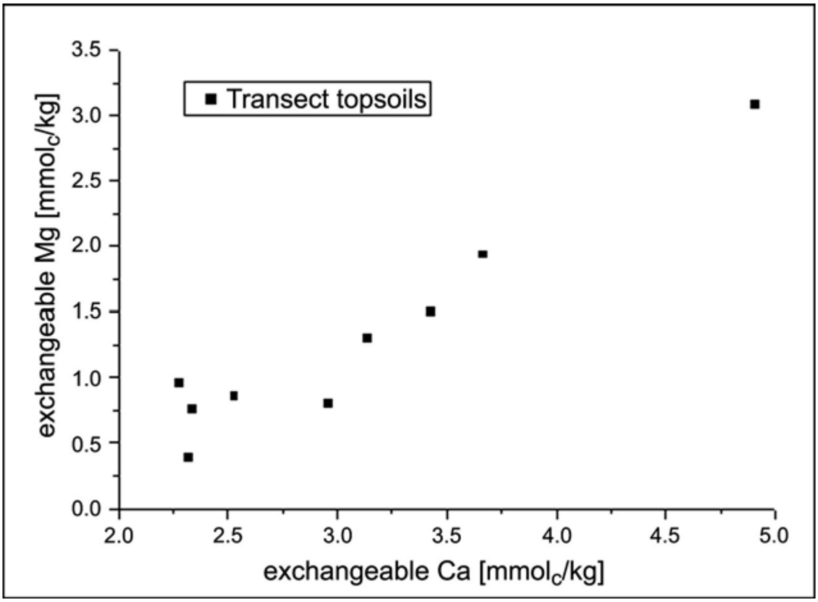


Fig. 2.4. Relations of exchangeable Ca and Mg ions in the topsoils in the Máze area

profiles. They are formed under the influence of a changing groundwater level.

The mineral soils contain only small amounts of the plant-available nutrients phosphorus and potassium. Phosphorus is mainly present as weakly soluble phosphate. The plant-available phosphorus content is mostly lower than 5 mg/kg; only a few of the case study sites show a content of 8–11 mg/kg. Moreover, the sites are poor in potassium. The plant-available content is less than 50 mg K/kg, indicating that potassium could be the limiting factor for the plant growth. Much higher content of phosphorus and potassium is stored in the organic layers (P up to ten times higher, K more than five times higher). Thus the organic layer may represent an important nutrient pool for the plants.

2.6 Conclusions

Soil geographical studies in the mountain birch forests of northern Fennoscandia, in particular on the western Finnmarksvidda, reveal a three-dimensional differentiation of the soil pattern. On a large scale, the distribution of the different soil types is controlled by the macro-climate and the vegetation (see Chap. 1), reflecting the increasing climatic continentality from the coast to the inland areas (from north to south) and the altitudinal decrease in the temperatures from the valley bottoms up to the mountain tops. The altitudinal differentiation of the climate, vegetation and soils is more striking than the zonal one. Within this framework the distribution of soil types and soil associations is governed by the lithologic, edaphic and orographic pre-conditions. Topography and relief have a strong influence on the moisture content of the soil, the vegetation cover and the soil development. On a small scale, moisture determines which soil type will develop.

On climatic and edaphic grounds podzols and nanopodzols are predominant (ca. 80 % of the studied soils). They occur in different variants, which can form transitions to other soil types, such as gley soils. Above the forest line, the podzol variants are often replaced by podzol regosols and syrosems.

A hypsometrical profile across the river valley at Máze as a case study shows a certain site concordance between the forest types and soil types and soil associations. Well-developed podzols (iron-podzols, iron-humus-podzols) are mainly found in moss-rich *Myrtillus* birch forests, while dwarf podzols (nanopodzols) are widespread in lichen-rich *Empetrum* birch forests near the forest line. The distribution of wet gley soils is almost restricted to meadow birch forests. However, the concordance is limited: the best-developed podzols, with profile depths up to 1 m, were observed in lichen-rich *Empetrum* birch forests. Moreover, nanopodzols are both widespread in lichen-rich birch forests and under dwarf shrub vegetation above the forest line.

All sites along the hypsometrical profile are characterized by a significant, but shallow, acidification of the soils. The topsoils of the podzol variants are strongly acidic. The transition to the B-horizon is marked by a pH increase of 0.5–1.0. The wet gley soils of the alluvial plain are moderately acidic. The effective cation exchange capacity (CEC) of the soils is quite low.

The mineral soils contain only small amounts of the plant-available nutrients phosphorus and potassium. A much higher content of P and K is stored in the organic layer of the soils, which can be an important nutrient pool for the plants.

A comparison with soils in other parts of Finnmark, Troms and the neighbouring areas of Finland and Sweden demonstrates that the results obtained in the case study are representative for large areas of northern Fennoscandia underlain by acidic rocks of the Fennoscandian Shield. Within the Caledonian mountain range bedrock, relief and climate are more variable, causing a large diversity of soil types. Where basic (Abisko mountains) and even ultramafic rocks (Bergsfjord mountains near Alta) occur, quite different soil types may develop. The thickness of the soil horizons is not only influenced by the properties of the substratum, but is also time-dependent. In areas which were deglaciated early, such as Varanger peninsula in northeasternmost Finnmark, the horizons can be relatively thick, as the soils had much more time to develop.

Acknowledgements. The authors are grateful to Linna Weber Müller-Wille (St. Lambert, Quebec, Canada) for language editing.

References

Bodenkundliche Kartieranleitung (1994) Bundesanstalt für Geowissenschaften und Rohstoffe (ed), Hannover, pp 1–392

Breburda J (1987) Bodengeographie der borealen und kontinentalen Gebiete Eurasiens. Giessener Abh Agrar Wirtschaftsforsch Eur Ostens Berlin, 148:1–176

Darmody RG, Thorn CE, Dixon JC, Schlyter P (2000) Soils and landscapes of Kärkevagge, Swedish Lapland. J Soil Sci Soc Am 64:1455–1466

Ellis S (1979) The identification of some Norwegian mountain soil types. Norsk Geogr Tidsskr 33:205–211

Ellis S (1980) Soil environmental relationships in the Okstindan Mountains, north Norway. Norsk Geogr Tidsskr 34:167–176

Ellis S (1983) Micromorphological aspects of arctic-alpine pedogenesis in the Okstindan Mountains, Norway. Catena 10:133–148

Ellis S (1985) An altitudinal sequence of podzolic soils, Hardangervidda, southern Norway. Norsk Geogr Tidsskr 39(3):141–154

Haapasaari M (1988) The oligotrophic heath vegetation of northern Fennoscandia and its zonation. Acta Bot Fennica 135:1–219

Jauhiainen E (1969) On soils in the boreal coniferous region. Central Finland–Lapland–northern Poland. Fennia 98(5):1–123

Jauhiainen E (1970) Über den Boden fossiler Dünen in Finnland. Fennia 100(3):1–32
Kühn K (1983) Botanische und bodenkundliche Bestandsaufnahme in Nord-Norwegen. Nat Mus 113:45–57
Meier K-D (1985) Studien zur Verbreitung, Morphologie, Morphodynamik und Ökologie von Palsas auf der Varanger-Halbinsel, Nord-Norwegen. Essener Geogr Arb 10:113–243
Meier K-D (1987) Studien zur periglaziären Landschaftsformung in Finnmark (Nordnorwegen). Jahrb Geogr Ges Hannover 1987 Sonderh 13:1–298
Meier K-D (1991) Beiträge zur kaltklimatischen periglaziären Landschaftsformung in der norwegischen Arktis und Subarktis. Courier Forsch- Inst Senckenberg 143:1–173
Meier K-D (1996) Studien zur Periglaziärmorphologie der Varanger-Halbinsel, Nordnorwegen (mit einem Vergleich Finnmark-Nordenskiöldland, Zentrales Westspitzbergen). Norden 11:1–405
Meier K-D (1997) Bemerkungen zur Verbreitung von Permafrostboden in Norwegisch-Lappland (Finnmark, Troms) anhand geomorphologischer und klimatischer Indikatoren. Norden 12:239–282
Meyer H-H, Knauer D, König K (1988) Ein boden- und vegetationsgeographisches Höhenprofil bei Åseral (Südnorwegen). Nat Mus 118:269–285
Moen A (1999) National atlas of Norway. Vegetation. Norw Mapping Authority, Hønefoss
Mosimann T (1981) Bodentypen und ihre Verbreitung im Bereich der Waldgrenze am NW-Rand der Finnmarksvidda, Norwegen. Norsk Geogr Tidsskr 35:209–226
Olsen L, Reite A, Riiber K, Sørensen E (1996) Finnmark Fylke, løsmassegeologisk kart i M 1:500 000 med beskrivelse (in Norwegian). Norges Geol Unders, Trondheim
Siedlecka A, Roberts D (1996) Finnmark Fylke, berggrunnsgeologi M 1:500 000 (in Norwegian). Norges Geol Unders, Trondheim
Stützer A (1995) Ein Vergleich von Art und Ausmaß der Stoffverlagerungen in Podsolen der Waldgrenzökotone Kanadas und Skandinaviens. Norden 10:73–84
Venzke J-F (1990) Beiträge zur Geoökologie der borealen Landschaftszone. Geländeklimatologische und pedologische Studien in Nordschweden. Essener Geogr Arb 21:1–254
Wielgolaski FE (1975) Functioning of Fennoscandian tundra ecosystems. In: Wielgolaski FE (ed) Fennoscandian tundra ecosystems, part 2. Animals and systems analysis. Ecological studies 17. Springer, Berlin Heidelberg New York, pp 300–326
Wielgolaski FE (1997) Fennoscandian tundra. In: Wielgolaski FE (ed) Polar and alpine tundra. Ecosystems of the world 3. Elsevier, Amsterdam, pp 27–83

3 Vegetation of the Mountain Birch Forest in Northern Fennoscandia

J. Wehberg, D. Thannheiser and K.-D. Meier

3.1 Introduction

The mountain birch forest in northern Fennoscandia (Väre 2001; Chap. 1) is known as the *regio betulina* or *regio subalpina* (Blüthgen 1960) and covers huge areas inland as well as some coastal areas. Hustich (1944) states that the northern limit of the mountain birch forests in that area is closely related to the 10 °C isotherm of July and that the distinct continental climate of north-eastern Europe suppresses the formation of a birch-dominated tree line (east and below the –20 °C isotherm of January or above the 30 °C annual amplitude). This may be due mainly to the survival of seedlings (cf. Chap. 5). Summer temperatures also influence the upper birch tree line in various mountain areas in Fennoscandia (see Chap. 1). Different types of ectomycorrhizae support the vitality of the mountain birch in this ecotone as well (Moriarty 1981; Magnússon and Magnússon 2001), while insect outbreaks are often detrimental to birch growth (see Chaps. 9, 12, 13). The present distribution of the Nordic mountain birch is dependent both on climate, introgressive hybridization with other birch species, and the influence of man in many ways (see e.g. Chap. 1).

This essay attempts to give an overview of the vegetation pattern and to assess the current state of the mountain birch forests in northern Fennoscandia. For this purpose a scientific investigation of the vegetation was carried out during the growth periods in 2001 and 2002. Around 400 relevés were taken and analyzed from the mountain birch forest of the Finnmarksvidda in Norway, the Utsjoki valley in Finland and the Abisko area in Sweden. The main focus was the delimitation of vegetational units and the creation of a synecological order in accordance with an appropriate typology. Dendrochronology was carried out on birch trees to analyze the growth variation in relation to climate (cf. Chap. 5), which in the long run, may also be of importance to the general plant species composition (cf. Chaps. 4 and 17).

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

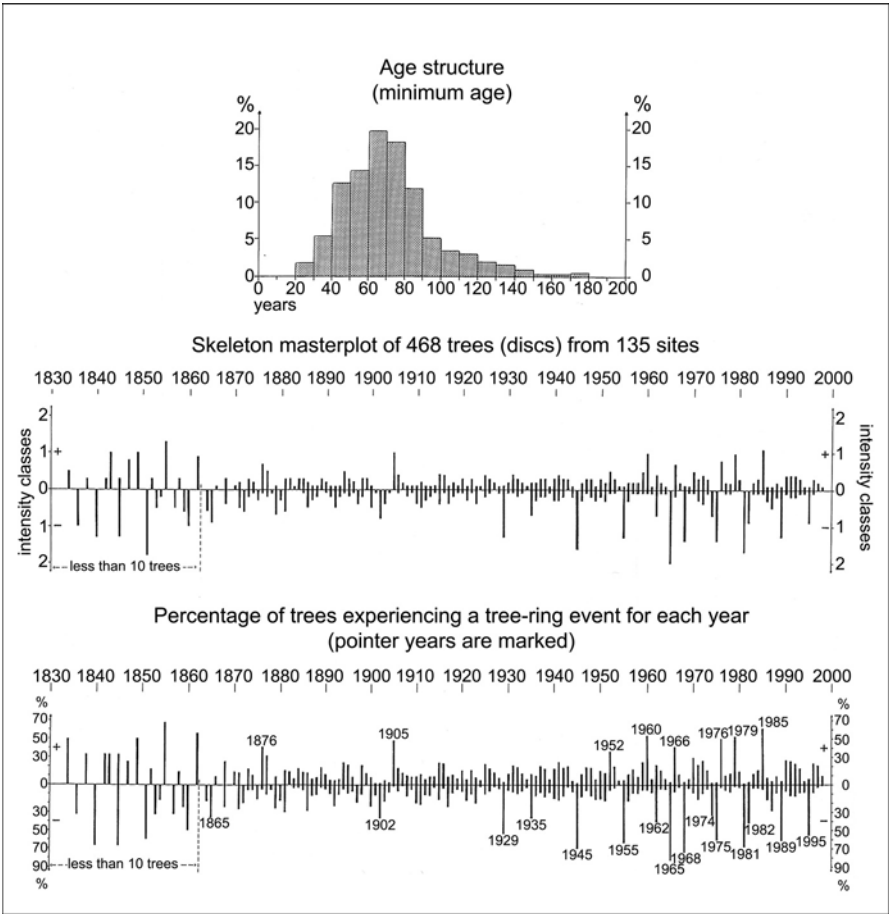
3.2 Study Site

The main study area is situated on the Finnmarksvidda in Norway and covers an area of around 2400 km^2 from the Finnish border to the Sautso Canyon south of Alta (see attached CD, Chap. 2, Fig. 2D). The climate conditions are clearly expressed in the vegetation pattern and zonation, although other factors, such as aspect to solar radiation and wind, type of bedrock and substratum, moisture content of the soil and anthropogenic effects (cf. Chaps. 1 and 2), have modified the vegetation pattern. Huge lichen-rich birch forests with a thick layer of *Cladonia* species exist in the southern part of the area. The continental climate and moderate reindeer density provide suitable conditions for this characteristic forest type which is rare today. The Kautokeino River flows through the area to the north. In the river valley, mainly in the Máze area, there are well-developed meadow forests with tall birches. This type of forest is experiencing anthropogenic change due to overcutting as well as overgrazing in the past. The expansive moss-rich *Vaccinium myrtillus* birch forests and the physiognomically rather similar *Cornus suecica* birch forests are common in the entire research area.

3.3 Dendrochronological Characteristics of the Northern Mountain Birch Forests in the Máze-Kautokeino Area

During the summers of 2001 and 2002, some 500 discs and around 2000 cores were taken from mountain birch trees in the Máze-Kautokeino area. The material originated from 164 localities on 19 W-E transects covering the whole research area (see attached CD, Table 3A). Three to 5 discs and 10–13 cores were collected per site (one disc or core per tree), about 50 cm above the ground. By April 2003, 468 discs from 135 localities had been analyzed using the skeleton plot method. With this method the tree-ring widths are not measured; instead each ring is visually compared with the previous rings. Years in which the ring width differs distinctly from that of the five preceding rings were registered as event years. Graphically, this results in a skeleton plot for each disc/tree. Five positive and five negative event classes were defined. The skeleton plots were transferred to a master plot that included all 468 trees (Fig. 3.1).

The investigated trees have minimum ages between 20 and 180 years. Younger trees are widespread in the birch forests, but could not be analyzed because the radii were too small. Even older trees exist; unfortunately, their age could not be established because the wood of the trunks was too rotten. The majority of the investigated trees have minimum ages of 40–90 years (76.6 %): 37.9 % are 60–80 years old. Only 11.3 % of the trees are older than


Age structure (minimum age)

Skeleton masterplot of 468 trees (discs) from 135 sites

Percentage of trees experiencing a tree-ring event for each year (pointer years are marked)

Fig. 3.1. Dendrochronological characteristics (age, pointer years) of 468 trees from 135 sites in the Joatkajavri-Suolovuopmi-Máze-Siccajavri area

100 years; many of these trees are already rotten at the core of the trunk. The wood starts to decay near the pith; at an age of 90–100 years the decay seems to accelerate. The low percentage of trees with a minimum age of 20–40 years (7 %) is striking.

The distribution and the minimum ages of the trunks of a root burl sprouting mountain birch tree were investigated near Máze by cutting all the trunks of a birch island (130 × 120 cm) which is representative of many birch islands in the area. By using discs, the minimum ages of 28 trunks could be determined. Only four trunks were too rotten. The age structure shows minimum ages between 3 and 67 years (Fig. 3.2). The trunks with the largest radii are the oldest; however, trunks with similar radii can have quite different ages, as two neighbouring trunks, 36 and 58 years old, clearly demonstrate. Whether the

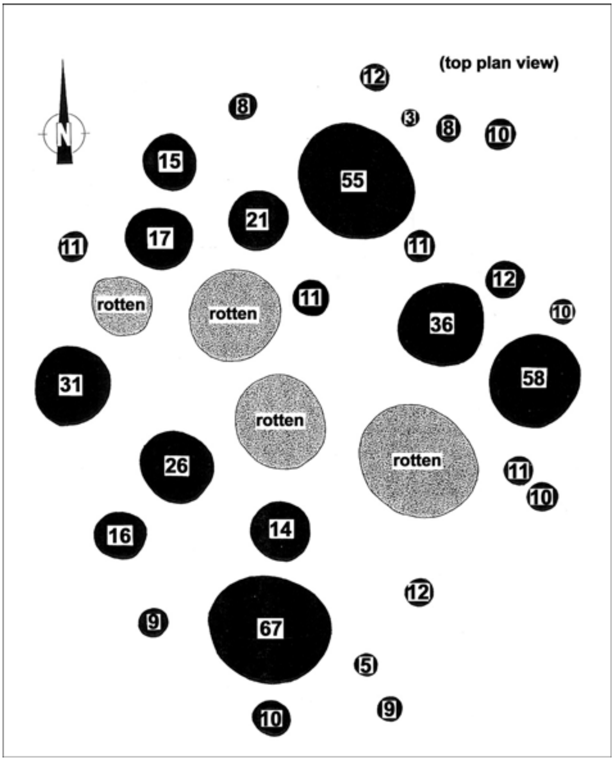


Fig. 3.2. Distribution and minimum ages (in years) of the trunks of a root burl sprouting mountain birch tree (birch island: 130 × 120 cm), Máze

rotten trunks are the oldest ones in the birch island cannot be determined by regarding their diametres only. The root stock of the birch tree is surely much older than the oldest living tree trunk. This clearly shows one main problem in determining the age of root burl sprouting birch trees: The most voluminous living tree trunk is not always the oldest one (which should be tested) and many generations of trunks of the same plant may have decayed in the past without leaving a trace, thus hiding a much higher age of the tree. Other difficulties in using year ring analysis for establishing the age of birch trees, including individual trees with single trunks, are caused by wood morphology, irregular growth, extreme and irregular growth reductions due to insect outbreaks (e.g. the larvae of *Epirrita autumnata*), missing rings, a relatively short life span compared to conifers such as *Pinus sylvestris*, and rapid decay of the dead wood.

The master plot (Fig. 3.1) reveals that there are more and stronger negative events than positive ones. Events which took place before 1863 were excluded because there were not enough trees available. A master plot showing, for each year, the percentage of trees that experienced a tree-ring event allows the identification of striking pointer years, here defined as years in which more

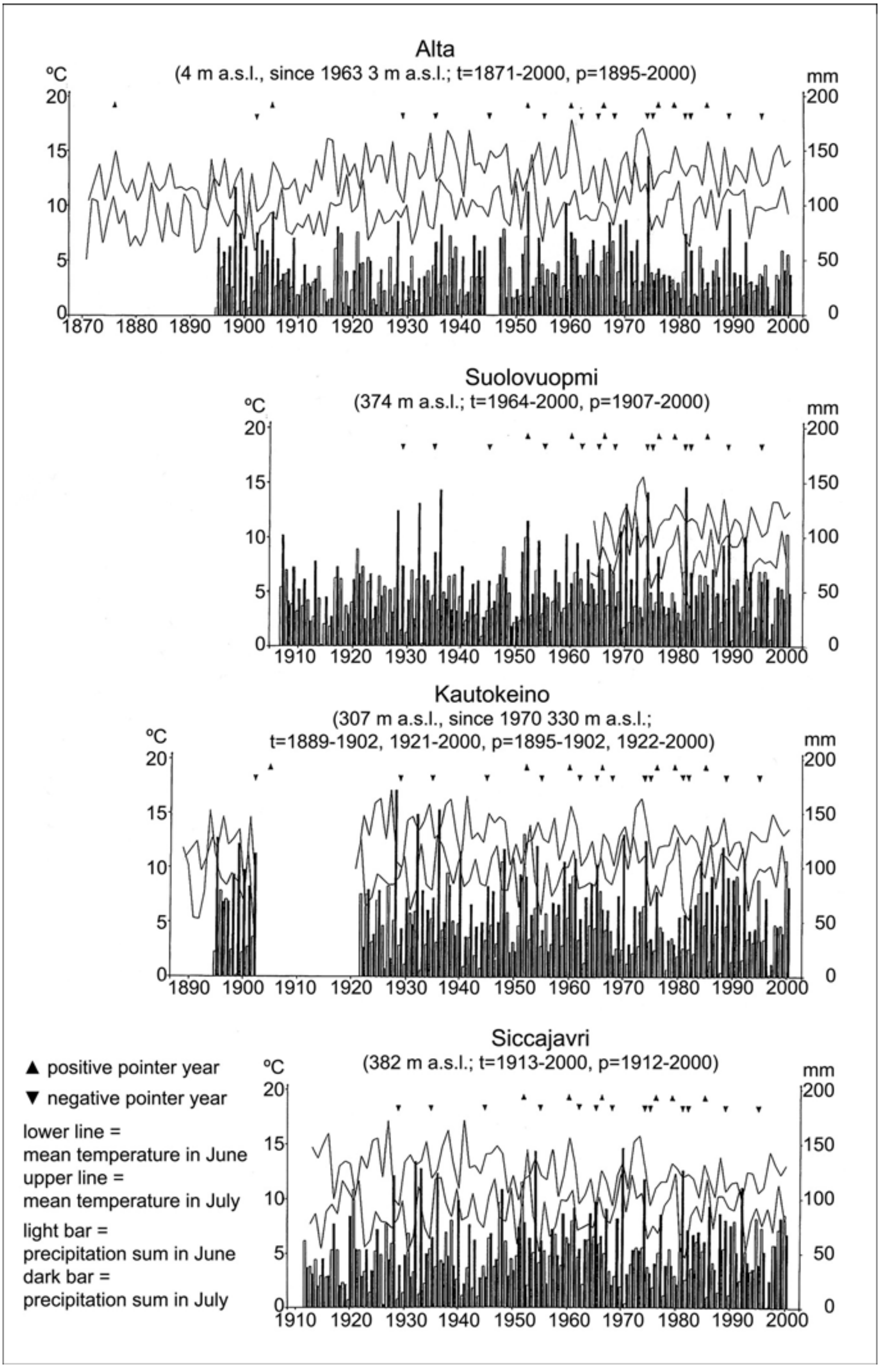


Fig. 3.3. Mean temperatures and precipitation for June and July compared to pointer years in the Alta-Siccajavri area

than 33.3 % of all trees reacted either positively or negatively to the environmental conditions. Following this definition, the years 1876, 1905, 1952, 1960, 1966, 1976, 1979 and 1985 can be classified as positive pointer years, whereas the years 1865, 1902, 1929, 1935, 1945, 1955, 1962, 1965, 1968, 1974, 1975, 1981, 1982, 1989 and 1995 are negative pointer years (see Fig. 3.1).

The pointer years were compared with the monthly climate data (temperature, precipitation), measured at the long-term weather stations at Alta, Suolovuopmi, Kautokeino and Siccajavri (cf. Chap. 1). These data reflect the increasing continentality of the climate from the north to the south of northern Fennoscandia. Obviously, the June and July temperatures have the greatest influence on the radial growth of the mountain birch trees, just as the summer temperature has on the upper climatic tree line found in mountain regions further south in Fennoscandia (see Chap. 1), while precipitation plays a minor role. To demonstrate this relation, the mean temperatures and precipitation for June and July, as well as the pointer years, are presented graphically (Fig. 3.3), and some correlations between tree-ring widths and climatic variables are presented in Chapter 5. The results can be explained by the short growth period for the birch trees. In the research area on the Finnmarksvidda buds normally burst in the middle of June. Although the leaves fall as late as the beginning or middle of September, depending on frost and aspect, the radial growth already ceases in late July at the end of the midnight sun period. The correlation between temperature and growth is better for negative than for positive pointer years; however, some pointer years, such as 1945, 1952, 1962 and 1976, cannot be explained sufficiently by the monthly climate data of the weather stations. This is not surprising, as the local site conditions (aspect, microclimate, soil, nutrients, stand structure, insect calamities, etc.) may influence the radial growth of the trees in a very complex way. Results on the use of tree-ring widths in Nordic mountain birch in relation to biomass and plant growth are discussed in Chapter 5.

3.4 Plant Sociological Studies

In the birch forests studied (Máze, Utsjoki and Abisko areas), vegetation surveys of the stands were made according to the method of Braun-Blanquet (1964). Sample plots were delimited in physiognomically homogeneous stands; the usual size was 100 m^2. Constancy tables were drawn up for improved appraisal of the respective forest association. In the tables, vegetation surveys containing similar species combinations were combined and classified on the basis of floristic likeness. The association, typified by characteristic species combinations, was selected as the basic vegetation unit. The associations introduced here are primarily typified by the dominating characteristic species. An additional sociological subdivision of the association into 'subassociations' and 'variants', based on characteristic species compositions, is possible. A formation of an association or subassociation not containing any differential species is designated 'typical association' or 'typical variant'. The floristic and structural definition of the forest communities is based upon the floristic composition of the herb, moss and lichen layers. To determine the clans, the authors used the floras of Nyholm (1954–1969), Arnell (1956), Elven (1994), Krog et al. (1994), Frisvoll et al. (1995).

The seemingly homogeneous monotony of birch forest vegetation is the reason for limited collection of material; nevertheless, an attempt was made to recognize and examine, as objectively as possible, the various vegetation types, and to obtain an overview of the numerous forms of vegetation in the study area. Furthermore, an attempt was made to determine regional differences in vegetation composition; for this purpose, optimal evenly distributed observation areas were recorded.

3.4.1 The Communities of the Mountain Birch Forest on the Finnmarksvidda

In the present study, six vegetational birch forest units at the rank of an association (Table 3.1) were defined: crowberry birch forest (*Empetro-Betuletum pubescentis*, Nordhagen 1943), lingonberry birch forest (*Vaccinio vitis-idaeae-Betuletum*, prov.), bilberry birch forest (*Vaccinio myrtilli-Betuletum*, prov.), dwarf cornel birch forest (*Corno-Betuletum*, Aune 1973), meadow birch forest (*Geranio-Betuletum*, Nordhagen 1928, 1943 emend. Dierßen and Dierßen 1982), and, finally, cloudberry birch forest (*Rubo chamaemorei-Betuletum*, prov.). These plant communities correspond partly to former taxonomic classifications, but in some cases were reclassified into provisional (prov.) subdivisions of the forest. For practical reasons, even coarser classifications of the mountain birch forest vegetation are often used, e.g. the four units: dry lichen–rich dwarf shrub (mainly *Empetrum* and *Vaccinium* species, both *V. vitis-idaea* and *V. myrtillus*) birch forest, moister moss-rich *Empetrum* birch forest, more fertile and moss-rich *Cornus* and bilberry (*V. myrtillus*) birch forest and meadow birch forest (see Chap. 4).

Overall, associations represent a complete structure of the entire mountain birch forest. The clearly distinguishable forest types are shaped by their specific conditions regarding ecological parameters. Thus, the synecological arrangement is influenced by the gradient of moisture and nutrient supply (Fig. 3.4). In the valleys, conditions mostly favourable for the vegetation prevail, due to the advanced soil development and good nutrient and water conditions (see Chap. 2). In addition, a thick snow cover protects the understorey vegetation against frost damage. The result is increasing biomass, which means a higher number of species and a denser cover of the different layers (apart from lichens and the lichen layer). In contrast, soil dehydration takes

Table 3.1. Shortened constancy table of mountain birch forest communities at Finnmarksvidda

	1[a]	2	3	4	5	6
No. of relevés	179	12	110	20	46	5
No. of species (total)	26.5	26.2	25.7	24.5	34.8	32.0
Height of birch (m)	3.8	4.3	6.1	7.3	7.4	3.2
Height of *Melanelia olivacea* (m)	0.5	0.3	0.7	0.9	0.8	0.9
Total coverage (%)	86.1	92.9	91.8	96.3	94.8	98.0
Tree layer (%)	29.1	47.5	45.4	55.4	57.2	30.0
Shrub layer (%)	7.7	4.1	5.4	5.4	18.7	12.0
Herb layer (%)	48.1	69.2	70.7	81.3	85.1	78.0
Moss layer (%)	20.8	46.3	48.3	50.1	26.1	56.0
Lichen layer (%)	39.9	20.1	6.2	2.2	0.4	1.8
Tree layer[b]						
Betula pubescens ssp. *czerepanovii*	V	V	V	V	V	V
Shrub layer						
Betula nana	IV	II	III	II	II	V
Juniperus communis	III	IV	IV	V	III	
Betula pubescens ssp. *czerepanovii*	II	III	II	II	III	
Salix glauca	+		+	I	III	II
Herb layer						
Empetrum nigrum ssp. *hermaphroditum*	V	V	V	V	II	V
Vaccinium vitis-idaea	V	V	V	IV	III	V
Vaccinium myrtillus	IV	II	V	V	II	V
Cornus suecica	+		III	V	II	V
Geranium sylvaticum			+	II	V	
Rubus chamaemorus				+	+	V
Deschampsia flexuosa	IV	II	V	V	III	II
Phyllodoce caerulea	IV	I	II	+	I	V
Festuca ovina	II	V	II	II	III	
Linnaea borealis	II	IV	IV	V	II	
Vaccinium uliginosum	III	II	IV	IV	III	V
Solidago virgaurea	II	II	IV	IV	V	I
Rubus saxatilis		I	+	+	IV	
Trollius europaeus			+		IV	
Saussurea alpina					IV	
Eriophorum angustifolium						V
Equisetum sylvaticum	+		+		+	IV
Trientalis europaea	II	II	III	II	III	III
Lycopodium annotium	II	III	II	III	II	
Pedicularis lapponica	+	I	III	II	II	
Equisetum pratense	+	+	I	II	III	
Calamagrostis purpurea	+		+		II	III
Equisetum arvense	+		+	+	III	
Carex nigra	+	+			II	III
Filipendula ulmaria					III	
Carex canescens				+		III
Andromeda polifolia					I	III

Table 3.1. (*Continued*)

Moss layer						
Polytrichum juniperinum	IV	IV	III	I	I	V
Pleurozium schreberi	IV	V	V	IV	III	I
Dicranum scoparium	IV	III	IV	II	II	III
Barbilophozia lycopodioides	III	II	IV	IV	III	I
Hylocomium splendens	II	III	IV	IV	III	
Sphagnum capillifolium					+	V
Dicranum elongatum				I		V
Sphagnum riparium						V
Bryum sp.	III	III	II	II	II	IV
Polytrichastrum alpinum	I	+	II	I	+	IV
Lichen layer						
Stereocaulon sp.	V	II	II		+	
Cladonia mitis	IV	III	III	II	+	
Cladonia stellaris	IV	III	II			
Cladonia uncialis	IV	II	II	+		III
Cladonia rangiferina	V	III	IV	II	+	I
Cladonia gracilis	IV	III	IV	II	+	IV
Cladonia arbuscula	II	III	II	+	+	IV
Crustose lichens	III	III	II	I	+	III
Cetraria nivalis	III	III	I			I
Cladonia cornuta	II	III	III	II	+	I
Nephroma arcticum	II	I	III	III	+	I
Cladonia coccifera	III	II	II	+	+	

---

[a] *1* Crowberry birch forest (*Empetro-Betuletum pubescentis*); *2* lingonberry birch forest (*Vaccinio vitis-idaeae-Betuletum*); *3* bilberry birch forest (*Vaccinio myrtilli-Betuletum*); *4* dwarf cornel birch forest (*Corno-Betuletum*); *5* meadow birch forest (*Geranio-Betuletum*); *6* cloudberry birch forest (*Rubo chamaemorei-Betuletum*)

[b] Degree of presence: + 1–10 %; *I* 11–20 %; *II* 21–40 %; *III* 41–60 %; *IV* 61–80 %; *V* 81–100 %

place very fast on the wind-prone plains and gentle slopes of glacio-fluvial sediments (sand and gravel). Especially in the inland areas, it leads to water (and nutrient) deficiency and to difficult growing conditions for some species. Therefore, the vegetation cover is scattered and dominated by lichens. The birches are very small and of the basal sprouting form. Reindeer grazing decimates the lichen cover at times and provokes an adjustment in the floristic composition. In some cases, the sparse vegetation cover and the ground infraction lead to deflation.

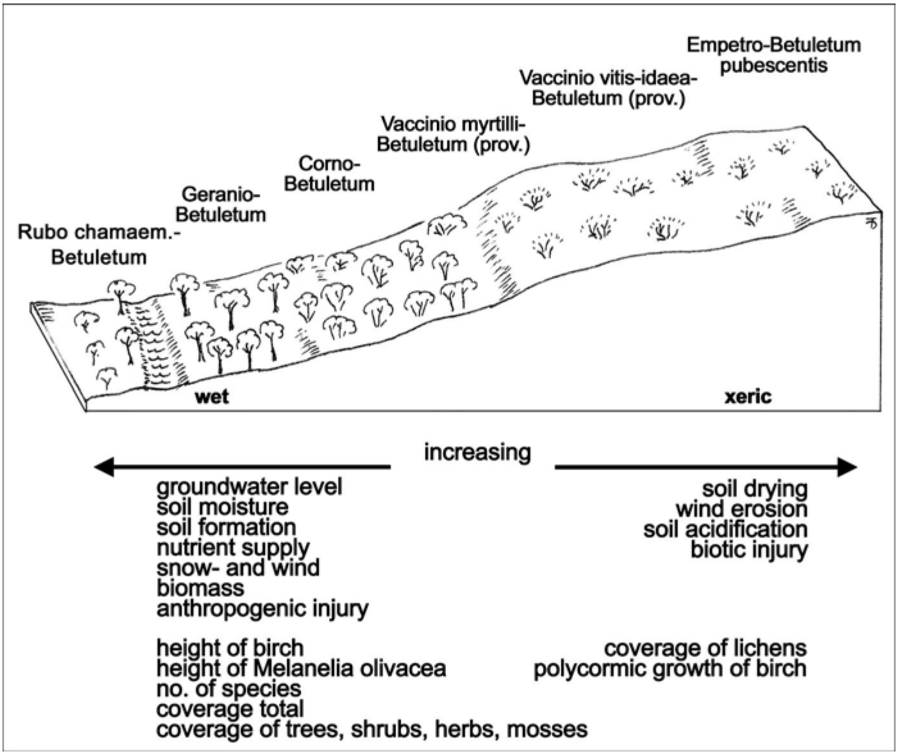


Fig. 3.4. Ecological zonation of mountain birch forest communities in northern Fennoscandia

3.4.1.1 The Crowberry Birch Forest: *Empetro-Betuletum pubescentis* (Nordhagen 1943)

This association includes the lichen and dwarf shrub-dominated forest, which prospers primarily in the inland parts of the research area. It spreads over plains and gentle slopes, at times over large areas. It is always found on dwarf podzol soil of sand or gravel, is very poor in nutrients and is xeric with a low pH value (see Chap. 2). The living conditions of the (partly subalpine) vegetation are also constricted by low snow cover during winter time (height of *Melanelia olivacea* in some cases only 10 cm; Sonesson 2001). This is caused by deflation of the snow cover in the wind-prone stands where there is no dense vegetation to slow the wind speed or to retain the snow.

The forests have a sparse and open aspect with a uniform physiognomy. The tree layer consists of small birches (less than 4 m on average) with little ground cover (30 % on average). The birches always grow from a basal sprout and at a regular distance from each other. These islands of birches sometimes reach a very old age, even if the individual trunks are much younger (see Sect. 3.3). The morphology of the trees is influenced by root competition and the acidic substratum (Verwijst 1988). The loose shrub layer includes mainly *Betula nana* and *Juniperus communis* (Table 3.1), while the young growth of birch takes place only in the birch islands. The field and bottom layers are dominated by dwarf shrubs and lichens at varying rates. In the entire association the vascular plants *Empetrum nigrum* ssp. *hermaphroditum* and *Vaccinium vitis-idaea* are very abundant (see CD, Table 3B). The moss layer covers around 20 % of the ground and contains rather light-demanding species such as *Polytrichum juniperinum*, *Barbilophozia lycopodioides*, *Dicranum fuscescens* and *Ptilidium ciliare*, and also *Pleurozium schreberi* and *Dicranum scoparium* (Vevle and Aase 1980). The lichen layer includes mostly *Stereocaulon* sp., *Cladonia stellaris*, *Cladonia rangiferina* and *Cladonia mitis*, and contains a high number of other species mainly of the genus *Cladonia*. The appearance of some species in the field layer is closely related to the shelter of the birch islands or to the open heath areas. For instance, *Empetrum nigrum* ssp. *hermaphroditum* and *Cladonia rangiferina* belong to the first group, while *Cladonia stellaris* and *Stereocaulon paschale* are found between the islands. Species such as *Vaccinium vitis-idaea* and *Cladonia mitis*, for example, are indifferent in this aspect. According to this floristic-ecological peculiarity, the field layer shows a mosaic-like pattern in some cases (Polunin 1936).

The association (see CD, Table 3B) was subdivided into subassociations according to the floristic composition and dominance of species. The subassociation of *Stereocaulon* sp can be seen as a strongly disturbed forest community, in which *Stereocaulon* sp. has replaced *Cladonia stellaris* due to heavy pasture pressure. It shows a close relationship to the subassociation of *Cladonia stellaris*. The grazing reindeer prefer the *Cladonia* species which are unable to regenerate as fast as *Stereocaulon* sp.. Furthermore, *Stereocaulon* sp. is not eaten by reindeer (Dierßen 1996).

3.4.1.2 The Lingonberry Birch Forest: *Vaccinio vitis-idaeae-Betuletum* (prov.)

This plant community of the lingonberry (*Vaccinium vitis-idaea*) is presented under the preliminary name *Vaccinio vitis-idaeae-Betuletum* (prov.= provisional). The main species is very common in all types of the mountain birch forest and occurs in forest types from the very xeric to the moist meadow forests. The lingonberry is able to spread by shoots and tolerates stands very poor in nutrients. It is found on sites with only a little snow cover where other dwarf shrubs disappear for thermic reasons (Nordhagen 1943). The thin snow layer (30 cm on average, Table 3.1) is constant and persists during winter time, but disappears quite early in the spring and leads to a longer growth period.

Under some special conditions the lingonberry covers large areas and creates its own community. These communities can be found, on the one hand, on ground moraine with sand or gravel and, on the other hand, on blocky soils. All stands have comparatively well-drained acidic substrata in common. Stands with a dominance of lingonberry are only small in area and rarely found at the research sites. In addition to the lingonberry, *Empetrum nigrum* ssp. *hermaphroditum*, *Pleurozium schreberi* and *Festuca ovina* are very frequent in this community, too (see CD, Table 3C). Two subassociations can be distinguished: the *Cladonia stellaris* and the *Hylocomium splendens*.

3.4.1.3 The Bilberry Birch Forest: *Vaccinio myrtilli-Betuletum* (prov.)

This community of the bilberry (*Vaccinium myrtillus*) is widespread in the whole mountain birch forest and often large in area. It is characterized by a fairly dense tree layer with a cover of 45 % on average (Table 3.1). The trees produce basal sprouts or are individuals with single trunks and are 6 m high on average. The shrub layer mainly includes *Juniperus communis* and *Betula nana* and is not densely scattered. The field layer is quite dense with a varying contingent of mosses and lichens, but the mosses are the main component (with one exceptional subdivision). *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Empetrum nigrum* ssp. *hermaphroditum*, as well as *Pleurozium schreberi* and *Deschampsia flexuosa* show a high degree of presence. The association is subdivided into three subassociations (see CD, Table 3D): the *Cornus suecica*, the typical, and the *Vaccinium vitis-idaea*.

Overall, the *Vaccinio myrtilli-Betuletum* (prov.) is located on more fertile stands than the associations discussed before. The soils are well developed podzols (iron podzols, iron–humus podzols; see Chap. 2), at least in the moss-rich types. It is found on various exposures from flat stands to steep slopes. The field layer has better conditions for its development because of a longer period of thick snow cover (*Melanelia olivacea*, on average 0.7 m height). Furthermore, the shelter of the canopy cover leads to a high coverage by the shade-tolerant bilberry.

The new definition as the *Vaccinio myrtilli-Betuletum* (prov.) focuses on the high dominance of bilberry in numerous stands of good nutrient supply and also good snow shelter during winter time in the oceanic as well as in the inland areas. It allows a good delimitation to the *Empetrum nigrum* ssp. *hermaphroditum* and *Cornus suecica*-dominated stands.

3.4.1.4 The Dwarf Cornel Birch Forest: *Corno-Betuletum* (Aune 1973)

The *Corno-Betuletum* is characterized by a high density of dwarf cornel (*Cornus suecica*; at times 75 % coverage). The main species has adapted to suboceanic conditions and an adequate water supply as well as good snow shelter during winter time (of *Melanelia olivacea*, height up to 2 m). For these reasons, the dwarf cornel community is concentrated in the centre and the northern parts of the research area in the Finnmarksvidda, but not in the southern inland parts. Under proper conditions this species may replace some other species, especially *Vaccinium myrtillus*. The soil is well-developed podzol (see Chap. 2), as is found in the *Vaccinio myrtilli-Betuletum*.

The tree layer of tall birches (more than 7 m) has a closed canopy cover of more than 50 % (Table 3.1). The shrub layer is scattered and contains *Juniperus communis*, *Betula nana* and some young growth of mountain birch. The field layer is very dense and has a well-developed moss layer, while lichens are rare. In addition to *Cornus suecica*, *Vaccinium myrtillus*, *Linnaea borealis*, *Deschampsia flexuosa* and *Empetrum nigrum* ssp. *hermaphroditum* are the most important species of the association. The nutrient-demanding species *Geranium sylvaticum* occurs frequently in this community and thus separates this community from the *Vaccinio myrtilli-Betuletum*. The association (see CD, Table 3E) can be divided into two subassociations of *Pleurozium schreberi* and *Gymnomitrion corallioides*, which are both quite similar in physiognomy, but not in floristic composition. Aune (1973) defined the *Corno-Betuletum* from Sør-Trøndelag in west-central Norway. This association is an important indicator for climatic changes in the research area. Thannheiser (1975) found no larger areas with a high incidence of *Cornus suecica* in the 1960s in the Máze area, but nowadays they are widespread on the river banks of the Altaelv and Mázejåkka and at suitable sites at higher elevations (see Chap. 17).

3.4.1.5 The Meadow Birch Forest: *Geranio-Betuletum* (Nordhagen 1928, 1943 emend. Dierßen and Dierßen 1982)

The *Geranio-Betuletum* belongs to the meadow forests of the river banks and moist sites in the upper elevations of the research area. At the base of slopes the groundwater recharge generates favorable conditions as well. However, the largest sites of the community are found in the Máze area at the Altaelv. The tree layer is always fairly dense (almost 60 %) and contains some *Salix* species besides the mountain birch. The birches are individuals with single trunks and reach a height of more than 7 m on average (Table 3.1), and in some cases 10 m and more. The shrub layer is well developed with young growth of birches, *Juniperus communis* and *Salix* species. The field layer is very dense, containing some tall herbs such as *Geranium sylvaticum*, *Solidago virgaurea*, *Rubus saxatilis*, *Trollius europaeus*, and *Saussurea alpina*. The moss layer is also noticeable, but not as thick as in the *Corno-Betuletum* or *Vaccinio myrtilli-Betuletum*. Overall, the *Geranio-Betuletum* gives a fresh and lush impression because of good abiotic conditions. The soil is mainly rambla and gley (see Chap. 2), relatively rich in nutrients and water. In the river sheds the soil is calcareous in places. In addition, a thick and enduring snow cover leads to favourable circumstances for the field layer during the winter period (*Melanelia olivacea*, height more than 0.7 m on average), and the closed canopy cover protects the understorey vegetation from dehydration. Therefore, this association is very rich in species (except lichens).

A subdivision of the association into two subassociations (see CD, Table 3F) reflects the floristic–physiognomic structure of the community. The first is the subassociation of *Trollius europaeus*, which represents the community richest in herbs. The field layer is dominated by the typical meadow forest species. *Trollius europaeus* occurs frequently and may reach a high density. This subassociation tends slightly to the more suboceanic areas, but is also found in the centre of the research area, as well as in the southern part. The second is the typical subassociation, in which no special species dominates. *Geranium sylvaticum* is abundant, but not dominant. This subassociation has a slight tendency to the more continental areas of the Finnmarksvidda. The descriptions of the *Geranio-Betuletum* by Nordhagen (1943), Dierßen and Dierßen (1982; compilation by Dierßen 1996) were satisfactorily replicated by the current investigations on the Finnmarksvidda, even though ferns are less abundant.

The *Geranio-Betuletum* is the community most affected by anthropogenic activities on the Finnmarksvidda because of logging. This is due to the occurrence of tall trees and, thus, a sufficient wood supply. In addition, these sites are often located in the vicinity of the settlements and easily accessible. In earlier times, the sites of the *Geranio-Betuletum* were degenerated by pasturing cattle in some areas (forest grazing); moreover, some were turned into arable land (Thannheiser 1977). Nowadays, hardly any stands remain in the Máze area that show the conceivable natural vegetation and that could be considered as undisturbed.

3.4.1.6 The Cloudberry Birch Forest: *Rubo chamaemorei-Betuletum* (prov.)

The association of the cloudberry (*Rubus chamaemorus*), called *Rubo chamaemorei-Betuletum*, differs from the other associations in several points. It occurs on peat soil where the ecological amplitude of the mountain birch reaches its limits. Because of the acidic, wet and unstable substratum, root respiration is confined as well as nutrient uptake and stabilization in the ground. Thus the tree layer is undersized with small, single trunk birches (3 m) and an open canopy cover (30 %), as can be seen in Table 3.1. In contrast, the shrub layer is well developed, mainly with *Betula nana*. Even if it tends to more inland areas, it has a competitive advantage due to the proper conditions regarding light and moisture. The field layer is clearly dominated (coverage over 25 %) by the main species, which is quite similar in ecological demands to the dwarf birch. *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Vaccinium myrtillus*, *Empetrum nigrum* ssp. *hermaphroditum* and *Cornus suecica* also occur frequently with sparse coverage at drier patches in the relevés (see CD, Table 3G). *Sphagnum capillifolium* reaches a high density at times. This association was found in the suboceanic part of the research site on bogs at the tree line, where it covers only small areas. *Melanelia olivacea* indicates a thick snow layer during the winter period. (Regarding the problems of final establishment of the associations, see Sects. 3.4.1.2 and 3.4.1.3).

3.5 Mountain Birch Forests in Northern Fennoscandia

The mountain birch forest represents the predominant landscape formation on the Finnmarksvidda, as well as in other parts of Norwegian, Swedish and Finnish Lapland. On a landscape level (see Chap. 4), the variations of the forest types differ only slightly, even though adjustments are visible in the floristic composition, due to variances in the climatic conditions. On a small scale, the physiognomy of the birches and the companion flora take different shapes according to ecological gradients.

In the Utsjoki valley (Finland) and in the Abisko area (Sweden), the mountain birch forests cover huge areas to the north of and above the coniferous zone. In the first area, some vascular plants (e.g. *Ledum palustre*) and mosses are very abundant; this is related to higher precipitation during the growing season.

In the Abisko area, the temperatures during the growing period are higher compared to Finnmarksvidda. The abundance of more suboceanic species such as *Cornus suecica* reflects this fact. Some forest types (especially the meadow forests, i.e. the *Geranio-Betuletum*) seem to be very fertile, corresponding to mild winters and thick snow cover. The lichen-dominated forest types (e.g. the subassociation of *Cladonia stellaris* of the *Empetro-Betuletum pubescentis*), which occur very frequently on the southern Finnmarksvidda, are scattered here. However, the forest communities very similar in composition to those described from the Finnmarksvidda can be found in the other research sites as well.

3.6 Conclusions

Dendrochronological analyses of 468 tree discs taken from 164 localities show that the vast majority of the trees have minimum ages between 40 and 90 years. By the age of 90–100 years the decay of the trunks accelerates. In most cases, the trunks with the largest radii are the oldest. A comparison of the master plot, showing striking pointer years, with selected climate data from the nearby weather stations, clearly demonstrates the potential of the birch rings as climate indicators. Though the results are preliminary as yet, and may be modified in the future, it is obvious that the June and July temperatures have a great influence on the radial growth of mountain birch trees (cf. Chap. 5). The reaction pattern controlled by the climate is strongly modified by the local site conditions (aspect, microclimate, soil, nutrients, stand structure) and episodic insect outbreaks (defoliation by the larvae of *Epirrita autumnata*; cf. Chaps. 4, 5, 9, 12). However, the intercorrelation of the factors is complex and not fully understood in detail. For the study area, the construction of a 200-year birch chronology seems possible. It could be a valuable supplement to the 2000-year northern Fennoscandian pine chronology, as each species displays an individual climate window. The widths of birch tree rings from a larger area can be used as proxy data for the June and July temperatures. This is of particular interest for the time before the weather was recorded systematically (in Finnmark about 1870) and for remote areas without weather stations. Whether or not the birch chronology can be extended farther into the past by including subfossil birch trees still has to be proved. Their trunks are poorly preserved and have therefore only been used for radiocarbon datings as yet. Subfossil trunks with better preserved wood may be enclosed in the permafrost of the numerous palsa bogs found on the Finnmarksvidda.

The six vegetation units defined after the phytosociological examination are representative for the entire mountain birch forest of northern Fennoscandia. All of them have been described in similar floristic composition by several authors (above all Hämet-Ahti 1963, Thannheiser 1975, Fremstad 1997; Nordisk Ministerråd 1998). Three communities have been renamed according to the international code of phytosociological nomenclature (Weber et al. 2000). Most of the communities reflect the potential natural vegetation. Disturbed forest communities are classified as the subassociation *Stereocaulon* sp. of *Empetro-Betuletum pubescentis.* On the Finnmarksvidda an apparent ecological gradient is visible from the northern parts to the more continental areas. The main reasons are less precipitation and higher temperatures in the inner parts, but other factors may be important as well. For example, the substratum seems to control the vegetation significantly. The lichen-rich birch forests are only found on well-developed podzols. However, the communities are also modified by anthropo-zoogenic impacts like woodcutting and reindeer grazing. Obviously, the elevation is less important for the development of the vegetation, as poor stands are found in both valley bottoms and at higher elevations.

In other areas of the mountain birch forest, such as Abisko (Sweden) and Utsjoki (Finland), the communities developed in a similar way with similar floristic composition. However, the lack of the lichen-rich forest types is striking. The reason may be higher precipitation in these areas and a less acidic substratum, creating unfavourable conditions for a dense lichen cover. Further investigations are needed for an evaluation of the different influences. On the other hand, the moss layer is well developed in the Finnish and the Swedish research areas. The occurrence of some species is restricted to special areas. *Phyllodoce caerulea* for example is more abundant on the Finnmarksvidda and, also, *Empetrum nigrum* ssp. *hermaphroditum* is more frequent there than in the Abisko area. Greater precipitation in the northern part of the Finnmarksvidda leads to good growth conditions for some species, such as *Cornus suecica.* The results are important not only from a syntaxonomic point of view. They also offer opportunities for an evaluation of the different biotic and abiotic factors and their importance for plant growth. For example, increasing precipitation leads to a more frequent occurrence of *Cornus suecica* in the *Vaccinium myrtillus*-dominated stands (see Chap. 17).

The consequences of reindeer grazing and climatic change are perceivable in an adjustment of the spectrum of species and, finally, of the communities. Local misuse in terms of wood cutting leads to the degeneration of *Geranio-Betuletum*. Due to climatic change and decrease in anthropogenic impact, the tree line is rising in some areas (see Chap. 17). To what extent the described communities will change or be replaced by others is not yet known. The succession may lead to an expansion of the moist forest to the disadvantage of the lichen-rich types (see Chap. 4). The sensitive ecosystem of the mountain birch forest with some specialized species is an important indicator of the environmental conditions. Therefore, it deserves special attention in the future.

Acknowledgement. The authors are grateful to Linna Weber Müller-Wille (St. Lambert, Quebec, Canada) for language editing.

References

Arnell S (1956) Illustrated moss flora of Fennoscandia. I. Hepatica, Lund

Aune EI (1973) Forest vegetation in Hemne, Sør-Trøndelag, western central Norway. K Norske Vidensk Selsk Mus Misc (Trondheim) 12:1–87

Blüthgen J (1960) Der skandinavische Fjällbirkenwald als Landschaftsformation. Petermanns Geogr Mitt 104:119–144

Braun-Blanquet J (1964) Pflanzensoziologie. Grundzüge der Vegetationskunde, 3rd edn, Springer, Vienna

Dierßen K (1996) Vegetation Nordeuropas. Ulmer Verlag, Stuttgart

Dierßen K, Dierßen B (1982) Kiefernreiche Phytozönosen oligotropher Moore im mittleren und nordwestlichen Europa. In: Dierschke H (ed) Struktur und Dynamik von Wäldern, Cramer, Vaduz, pp 229–331

Elven R (1994) Lid's Norsk Flora, 6th edn (in Norwegian). Det Norske Samlaget, Oslo

Fremstad E (1997) Vegetasjonstyper i Norge (in Norwegian). Norsk Inst Naturforsk Temah (Trondheim) 12:1–279,

Frisvoll A, Elvebakk A, Flatberg KI, Økland R (1995) Sjekkliste over norske mosar. Vitskapleg og norsk namneverk (in Norwegian). Norsk Inst Naturforsk Temah (Trondheim) 4:1–104, Hämet-Ahti L (1963) Zonation of the mountain birch forests in northernmost Fennoscandia. Ann Bot Soc "Vanamo" (Helsinki) 34(4):1–127

Hustich I (1944) Några synpunkter på skogsgränserna i nordligaste Skandinavien (in Swedish). Svenska Skogsvårdsför Tidsskr 42:132–141

Krog H, Østhagen H, Tønsberg T (1994) Lavflora. Norske busk-og bladlav (in Norwegian). Universitetsforlaget, Oslo

Magnússon SH, Magnússon B (2001) Effect of enhancement of willow (*Salix* spp.) on establishment of birch (*Betula pubescens*) on eroded soil in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 317–329

Moriarty F (1981) Ecology, epidemiology and effects of some sheathing (ecto-) mycorrhizal associations. Inst Terr Ecol Annu Rep 1981, Nat Environ Res Council, Great Britain, pp 35–39

Nordhagen R (1928) Die Flora und Vegetation des Sylenegebietes. Nor Vidensk Akad Skr Oslo 1:1–612

Nordhagen R (1943) Sikilsdalen og Norges fjellbeiter. En Plantesosiologisk monografi (in Norwegian). Berg Mus Skr 22:1–607

Nordisk Ministerråd (1998) Vegetationstyper i Norden. Tema Nord (Copenhagen) 510:1–706 (in Swedish)

Nyholm E (1954–1969) Illustrated moss flora of Fennoscandia II. Musci Fasc 1–6, Stockholm

Polunin N (1936) Plant succession in Norwegian Lapland. J Ecol 24:372–391

Sonesson M (2001) Ecology of some epiphytic lichens on the mountain birch. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and the biosphere series 27. UNESCO, Paris and Parthenon, New York, pp 63–70

Thannheiser D (1975) Vegetationsgeographische Untersuchungen auf der Finnmarksvidda im Gebiet von Masi/Norwegen. Westfälische Geogr Stud (Münster) 31:1–178,

Thannheiser D (1977) Subarctic birch forests in Norwegian Lapland. Natural Can 104:151–156

Väre H (2001) Mountain birch taxonomy and floristics of mountain birch woodlands. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and the biosphere series 27. UNESCO, Paris and Parthenon, New York, pp 35–46

Verwijst T (1988) Environmental correlates of multiple-stem-formation in *Betula pubescens* ssp. *tortuosa*. Vegetatio 76:29–36

Vevle O, Aase K (1980) Om bruk av økologiske faktortall i norske skogplantesamfunn. In: Baadsvik K, Rønning OI (eds) Fagmøte i vegetasjonsøkologi på Kongsvoll 1980. K Norske Vidensk Selsk Mus Rapp Bot Ser 5 (Trondheim):178–201 (reprinted as Telemark distriktshøgsk, skr 52) (in Norwegian)

Weber HE, Moravec J, Theurillat J-P (2000) International code of phytosociological nomenclature, 3rd edn. J Veg Sci 11:739–768

4 Biomass and Production on a Landscape Level in the Mountain Birch Forests

H. Tømmervik, F.E. Wielgolaski, S. Neuvonen, B. Solberg
and K.A. Høgda

4.1 Introduction

Low summer temperatures limit the distribution of mountain birch in latitude and altitude, but it was found early (Helland 1912) that the Nordic mountain birch normally grows at lower summer temperatures than spruce and pine in Fennoscandia (see Chap. 1). Odland (1996) stated that the average maximum temperature isotherm 13.2 °C of the four warmest months correlates better with the mountain birch forest line than any other temperature. There is often a decrease in the final height of mountain birch trees with increasing elevation which is caused by several environmental factors often even more important than temperature, e.g. strong winds, reduced length of the growing season etc. The nutrient and water conditions are also very important for growth. Generally, there is an increasingly limited nitrogen supply with elevation, often also a low humus content in the soil (in other cases, an extremely high content), causing a low water holding capacity.

Most of the Fennoscandian birch forests are relatively oligotrophic and dry with a ground vegetation often closely related to the grass–*Vaccinium* heaths under more extreme climatic conditions with no trees. In northern Fennoscandia, reindeer lichens and *Empetrum hermaphroditum* often dominate the understorey of birch forests. Väre (2001) gives a classification of mountain birch woodlands, while Wehberg et al. (see Chap. 3) have presented a new classification of the Nordic mountain birch communities at Finnmarksvidda in northernmost Norway according to plant sociological methods. The lowest production is found on a lichen-rich type common in the north-eastern inland districts of Fennoscandia and in the inner parts of the mountain region. The mountain birch on this type is on average only 2–3 m tall. This is a type extensively grazed by reindeer. Somewhat higher productivity is found in more grass- (*Deschampsia flexuosa*) and moss-rich woodlands, which are common on relatively oligotrophic ground in suboceanic districts

---

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

and often extensively grazed by sheep, e.g. in Iceland. On this type the trees are on average 4–7 m tall. Even higher production is normal in the forest type rich in low herbs, which is most common in mesotrophic–eutrophic grounds in the suboceanic mountain regions of Norway and Iceland. The birches easily reach more than 10 m in southern, elevated regions of Fennoscandia. However, even taller trees are common in the rich tall herb mountain birch forest type, which is most common in lower parts of suboceanic valleys on eutrophic ground (cf. the humidity sections presented in Chap. 1). Production is considerably higher in the birch forests than on the alpine heaths, mainly due to the higher temperatures and acclimatization to this temperature.

Herbivory of mountain birch is caused by both invertebrates and vertebrates (see the herbivory section and also Chaps. 5, 17). Strong grazing by sheep is one important reason for ecosystem degradation and strongly reduced birch woodlands in Iceland (Aradottir and Arnalds 2001). Hard reindeer browsing, particularly in the fragile, nutrient-ppor and lichen-rich mountain birch woodland, causes similar degradation of the ecosystem. The lichen cover has been strongly reduced, e.g. in parts of Finnmarksvidda, over the last 40 years (Tømmervik and Lauknes 1987; Johansen and Karlsen 1996; Gaare and Tømmervik 2000; Tømmervik et al. 2004; Chap. 17) and, in some cases, new birch growth is also browsed by animals. In other cases, particularly by somewhat reduced reindeer grazing after much of the lichen mat is destroyed and open soil has become common, there is a tendency toward increased sprouting of mountain birch (Gaare and Tømmervik 2000; Tømmervik 2000).

However, the sprouting of mountain birch may also have been caused partly by increased precipitation favouring birch growth (see Chap. 1). The scenarios predict continued increased precipitation, per decade in the order of 1.5 % in north-eastern Fennoscandia, and 4–5 % in north-western Norway (Hanssen-Bauer and Førland 2000). Increased precipitation, together with an increment in the winter and spring temperature, predicted to be 0.4–1.0 °C per decade over the next 50 years in inland, north-eastern Fennoscandia (Hanssen-Bauer and Førland 2000), may also cause more ice crusts on the lichen heath and death of the reindeer lichens (Wielgolaski 2001). The most pronounced climate changes are foreseen to occur throughout the next century at northern latitudes and in winter (Post and Stenseth 1999).

The higher precipitation mainly comes as snow in interior parts of northern Fennoscandia and in mountain areas, despite higher temperatures (cf. Chap. 1). This may have caused later spring development in the areas mentioned and sometimes also shorter growing seasons (Høgda et al. 2001).

In addition to abiotic environmental conditions, genetic variations between individual birch trees will cause variation in growth (Wang and Tigerstedt 1996), often due to ecotypic variation (see Chap. 7). *Betula pubescens* commonly hybridize with *B. nana*, particularly at higher elevations and in northern Fennoscandia (Vaarama and Valanne 1973). Low *B. nana*-like trees with relatively small leaves represent food of a poorer quality for herbivores than large-leafed trees (Senn et al. 1992). They also sprout later than large-leafed trees. Defoliation by herbivores or by experimental clipping in winter and spring also delayed the bud break and weakened the growth, but produced larger leaves (Raitio et al. 1994; Senn and Haukioja 1994). The latter authors also found that clipping of only one quiescent apical bud from the tips of all branches in winter induced the whole ramet to produce large, water-rich, short shoot leaves.

4.1.1 Live Aboveground Biomass Estimations

Various authors have estimated the live aboveground biomass at different locations of mountain birch forests within Fennoscandia (Table 4.1), and these figures have been used for biomass estimates at the Norwegian sites Máze and Målselv in the present study (see Sect. 4.3.2).

Dahlberg (2001) estimated the tree biomass for forested vegetation in Abisko in northern Sweden (forest and snow-protected heath and meadow) to be 770–2750 g/m², depending on the richness of the forests. Elkington and

Table 4.1. Biomass estimation data from different locations within Fennoscandia

Forest type	Biomass tons/km² tree level	Biomass in m³/ha growing stock
Meadow forests in Máze	2307[a]	23[b]
Meadow forests in Målselv	2307[a]	28[b]
The *Cornus-Myrtillus* birch forests (CMB) and the moss-rich *Myrtillus* birch forest (MMB) in Máze	2307[a]	23[b]
The *Cornus-Myrtillus* birch forests (CMB) and the moss-rich *Myrtillus* birch forest (MMB) in Målselv	2307[a]	28[b]
The moss-rich *Empetrum* birch forest (MEB)	2120[c]	11[b]
The lichen-rich *Empetrum* and *Vaccinium* birch forest (FEB and FMB), lichen cover>50 %	957[d]	11[b]
Lichen biomass in the lichen-rich *Empetrum* and *Vaccinium* birch forest (FEB and FMB), lichen cover>50 %	1961: 500[e] 2000: 200[f]	

[a] Kjelvik and Kärenlampi (1975) (living birch tree biomass aboveground)
[b] Sihvo (2002)
[c] Starr et al. (1998)
[d] Bylund and Nordell (2001)
[e] Lyftingsmo (1965)
[f] Gaare and Tømmervik (2000)

Jones (1974) estimated the biomass of a birch forest stand in Greenland to be 4850 g/m^2, which was many times more than the estimates in Abisko and Vuoskojarvi. According to Bylund and Nordell (2001), the productivity of the Greenland forest is significantly higher than the productivity of the Abisko forest. Dahlberg (2001) estimated the average biomass of the shrub layer to be 368 g/m^2 for all forest types. Wielgolaski et al. (1981) estimated the phytomass of the field layer and bottom layer to be 413 and 535 g/m^2 in Kevo in northern Finland.

4.1.2 Biomass and Leaf Area Index at Individual Tree or Stand Levels

Vegetation biomass and leaf area index (LAI) play an important role in regional and global carbon cycles. The LAI is an important structural characteristic of ecosystems and is strongly correlated with many terrestrial ecosystem processes such as evapo-transpiration and total net primary production. There seems to be a good correlation between the height of the plants and the maximum LAI, which generally also means a negative correlation with increasing latitude and altitude. Normally, maximum LAI was found at the time of peak aboveground standing crop. Maximum LAI occurred later in the understorey of forest tundra than at sites in extreme alpine and arctic tundra (Wielgolaski et al. 1981). This indicates earlier senescence in the plants under extreme conditions.

Moreover, the accurate estimation of regional terrestrial ecosystem carbon balance is critical in formulating national and global adaptation and mitigation strategies in response to global climate change (cf. Chaps. 5, 6). Since the circumpolar ecosystems are particularly sensitive to climate change (Chapin and Shaver 1996; Jonasson et al. 1996; Robinson et al. 1998), there is a need for improved estimates of biomass in these areas. In several countries, the biomass of productive forests is operationally monitored through objective sampling surveys. However, these methods are not adapted, or applied, to the mountain ecosystems where the vegetation types differ. Currently, the only quantitative biomass and LAI data available for the Scandinavian mountain ecosystem were obtained through estimations on tree or plot level for limited areas (Sveinbjörnsson 1987; Starr et al. 1998; Bylund and Nordell 2001; Dahlberg 2001). The most common method for predicting biomass and LAI for specific trees and stands is modelling through allometric relationships, mainly with tree variables, but also with stand and site information (e.g., Marklund 1988; Korsmo 1995; Wang et al. 1996; Johansson 1999).

4.1.3 Biomass on Landscape and Regional Levels Using Remote Sensing

The allometric relationships for biomass and LAI estimations are applicable only for single tree approaches. For area-based estimates, one has to either make estimations for many trees and add them up for an area, or relate area measurements to some stand or site variables. Furthermore, Ståhl et al. (1999) suggest that due to access difficulties and the high variability of the ecosystem, purely field-based methods become expensive in the mountain areas. An alternative to using only field measurements might be to add auxiliary information, such as optical aerial and satellite remote sensing data to extrapolate the estimations over larger areas. This approach can increase the accuracy of the statistical estimates for a given area where field plots are available (Hagner 1990; Reese and Nilsson 1999; Steininger 2000). Satellite observations of vegetation have provided global coverage with relatively high spatial resolution and consistent time coverage since the early 1980s. Forest biomass cannot be directly measured from space yet, but, as we demonstrate in this chapter, remotely sensed greenness can be used as an effective surrogate for biomass on decadal and longer time scales in regions of distinct seasonality, as in the north. Year-to-year changes in production are quite small, about two orders of magnitude smaller than the biomass pool. At decadal and longer time scales, the production change can be considerable because of the accrual of differences between gains and losses. Potentially, these can be observed as low-frequency variations in greenness, in much the same way as greenness changes at centennial and longer time scales are suggestive of successional changes (Zhou et al. 2001). In addition, the use of remote sensing data will provide the spatial distribution of biomass or LAI in the form of a map which is easy to analyse in a geographical information system (GIS) together with other thematic information.

The study in Dahlberg (2001) shows that optical satellite data can be useful for quantification of alpine vegetation in the Swedish mountain ecosystem. It was found that red and near-infrared bands were important variables in the multiple regressions of biomass and LAI. However, it was not always obvious whether the model described biomass (or LAI) or some ground variable (e.g. rock cover, topography). Therefore, one should use not only spectral data in the models, but also topography and discharge models for the watershed area to describe the water availability in each pixel. Another possibility is to estimate biomass by vegetation type mapping (Tømmervik et al. 1997, 1998, 2003, 2004). Myneni et al. (2001) monitored the biomass and carbon stocks on a regional and circum-polar level using the remote sensing GIMMS-NDVI data set with satisfactory results.

The aim of the present study is to assess the information about biomass extracted by remote sensing satellites in northern Fennoscandia on a regional level and in Máze and Målselv on a landscape level with ground measurements. We will also present and discuss other results from investigations in

Abisko (Dahlberg 2001) and northernmost Finland (Juntunen et al. 2002; Kukkonen 2002; Sihvo 2002).

4.2 Methods

Satellite image-aided analysis of forest production provides spatially complete coverage that can be used to interpolate traditional ground-based observations. Satellite sensors are capable of measuring broad-scale changes in the landscape that can be associated with changes in biomass-specific plant crops or land cover types, and can describe land cover conditions and phenological stages. The normalized difference vegetation index (NDVI) has become the primary tool for monitoring vegetation changes and is used to interpret both climatic/weather and human impacts on the biosphere. The NDVI (1) is defined as:

$$\mathrm{NDVI} = (\mathrm{Ch2}-\mathrm{Ch1})/(\mathrm{Ch2}+\mathrm{Ch1}) \tag{4.1}$$

where Ch1 and Ch2 represent data from the satellite NOAA AVHRR channels 1 and 2 respectively. For Landsat TM or IRS-1D the near-infrared (Ch2) and red channel (Ch1) are used to calculate this index. Another possibility is to estimate biomass by vegetation mapping using remote sensing

In this chapter, we have chosen to use the NDVI method to map the broad changes in the biomass on the regional level. On the landscape level (Máze and Målselv), we have chosen to use area estimates of the different forest types extracted from vegetation-type maps based on various remote sensing platforms (Table 4.2) or statistics, which were compiled or produced in this project in order to calculate the total biomass for the forests within these two areas. In addition, we used biomass data from several authors mentioned in Table 4.1.

The vegetational birch forest units used in Tables 4.1, 4.3, 4.4, and 4.5, 4.6 correspond to the following units in Chapter 3 (see also Chap. 17): the meadow birch forest corresponds to meadow birch forest (Geranio-Betule-

Table 4.2. Remote sensing data used in this project

Remote sensing sensor and platform	Year and date of acquisition
Aerial BW photographs	1954–1960
Landsat MSS/TM/ETM+	1973, 1978, 1980,1982, 1987, 1990, 1996, 2000
IRS 1D	1999
NOAA AVHRR (GIMMS data set)	1982–1999

Table 4.3. Live aboveground biomass estimations (birch forests) within the study area of Máze 1961 (see Table 4.1 for more information)

Forest type	Biomass in 1000 m^3 growing stock	Máze 1961			
		Area (km^2)	Tree biomass (tons)	Shrub biomass (tons)	Field-layer biomass (tons)
Meadow forests	991	431	1,019,315	158,770	230,820
The *Cornus-Myrtillus* birch forests (CMB) and the moss-rich *Myrtillus* birch forest (MMB)	472	205	484,825	75,416	84,638
The moss-rich *Empetrum* birch forest (MEB)	831	755	906,000	277,847	311,823
The lichen-rich *Empetrum* and *Vaccinium* birch forest (FEB and FMB), lichen cover>50 %	1115	1014	948,090	373,109	418,734
Lichen biomass					506,942
Total	3409	2481	3,358,230	885,142	1,552,957

Table 4.4. Live aboveground biomass estimations (birch forests) within the study area of Máze 2000 (see Table 4.1 for more information)

Forest type	Biomass in 1000 m^3 growing stock	Máze 2000			
		Area (km^2)	Tree biomass (tons)	Shrub biomass (tons)	Field-layer biomass (tons)
Meadow forests	1166	507	1,199,055	186,555	271,214
The *Cornus-Myrtillus* birch forests (CMB) and the moss-rich *Myrtillus* birch forest (MMB)	1835	798	1,887,270	293,724	329,642
The moss-rich *Empetrum* birch forest (MEB)	1436	1305	1,566,000	480,279	539,009
The lichen-rich *Empetrum* and *Vaccinium* birch forest (FEB and FMB), lichen cover >50 %	961	874	817,190	321,509	360,824
Lichen biomass					174,733
Total	5398	3560	5,469,515	1,282,067	1,675,422

Table 4.5. Live aboveground biomass estimations (birch forests) within the study area of Målselv 1978 (see Table 4.1 for more information)

Forest type	Biomass in 1000 m^3 growing stock	Målselv 1978			
		Area (km^2)	Tree biomass (tons)	Shrub biomass (tons)	Field-layer biomass (tons)
Meadow forests	2021	722	1,707,530	265,549	298,021
The *Cornus-Myrtillus* birch forests (CMB) and the moss-rich *Myrtillus* birch forest (MMB)	2789	996	2,355,540	366,638	411,472
The moss-rich *Empetrum* birch forest (MEB)	767	697	836,400	256,496	287,861
Total	5577	2415	4,899,470	888,683	997,354

Table 4.6. Live aboveground biomass estimations (birch forests) within the study area of Målselv 1999 (see Table 4.1 for more information)

Forest type	Biomass in 1000 m^3 growing stock	Målselv 1999			
		Area (km^2)	Tree biomass (tons)	Shrub biomass (tons)	Field-layer biomass (tons)
Meadow forests	2996	1070	2,530,550	393,797	441,951
The *Cornus-Myrtillus* birch forests (CMB) and the moss-rich *Myrtillus* birch forest (MMB)	2467	881	2,083,565	324,392	364,060
The moss-rich *Empetrum* birch forest (MEB)	956	869	1,042,800	319,866	358,980
Total	6419	2821	5,656,915	1,038,055	1,164,991

tum). The *Cornus-Myrtillus* birch forests (CMB) and the moss-rich *Myrtillus* birch forest (MMB) correspond to dwarf cornel birch forest (Corno-Betuletum), the moss-rich *Empetrum* (crowberry) birch forest, and the bilberry birch forest (Vaccinio myrtilli-Betuletum). In the lichen-rich *Empetrum* and *Vaccinium* birch forest (FEB and FMB), lichen over>50 % lichen biomass corresponds to crowberry birch forest (Empetro-Betuletum pubescentis) and lingonberry birch forest (Vaccinio vitis-idaeae-Betuletum, prov.). The methods used to produce these vegetation-type maps are a "hybrid", unsupervised/supervised classification algorithm used with satisfactory results in Pasvik (Norway) and Nikel-Pechenga in Russia (Tømmervik et al. 1997, 1998). The overall classification accuracy of the maps has been reported to more than 80 % (Tømmervik and Lauknes 1987; Tømmervik et al. 2003).

4.3 Results

4.3.1 Change in the Biomass Production on a Regional Level

In this section, we used data from the GIMMS NDVI data set and data from the Landsat ETM+ and IRS satellites. We used the GIMMS data set to assess the change in maximum NDVI on a regional level (Fennoscandia). Figure 4.1

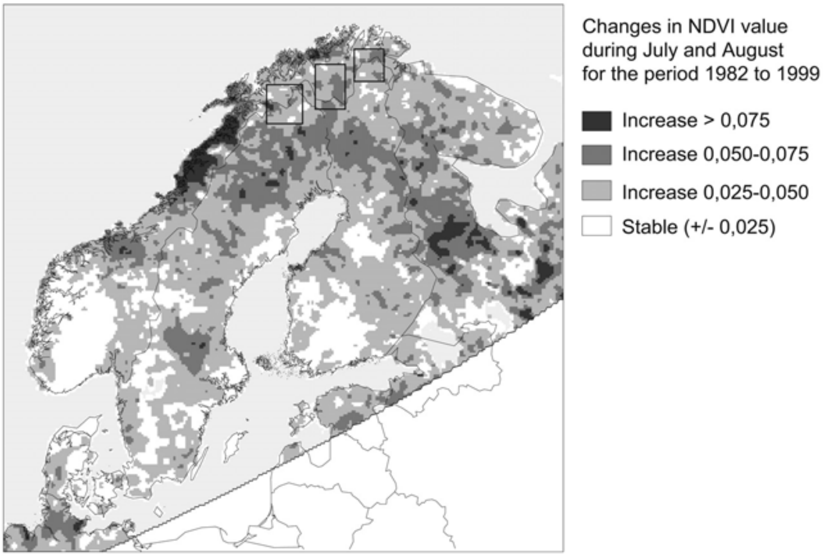


Fig. 4.1. Changes in NDVI values during July and August for the period 1982–1999. *Dark areas* show a significant increase. *White areas* show a stable situation. *Rectangles* in the map indicate the study areas of Målselv-Abisko (*left*), Máze (*centre*) and Kevo (*right*)

illustrates the trend in maximum NDVI values during the period 1982–1999. It can be observed that the trend is towards a higher peak NDVI value in most of the northern part of Fennoscandia. For the study areas in Målselv and Máze in Norway, Abisko in Sweden and Kevo in Finland, the trends are positive and causes for this could be increased extent of the mountain birch forests and changes in the vegetation cover from lichen-dominated cover to more heather vegetation and scrubs. This is especially highlighted in the Máze (Kautokeino) area.

4.3.2 Biomass Estimations on a Landscape Level

We have chosen to use the area estimates of the different forest types in Máze and Målselv extracted from satellite-based vegetation cover maps which were compiled (Johansen and Karlsen 2000; Tømmervik 2000) or produced in the HIBECO project for the two areas in order to map the change in the extent of the forests and to calculate the total biomass for the forests. In Tables 4.3 and 4.4 we can observe that the area of forests in Máze has increased from ca. 2400 km^2 in 1961 to more than 3500 km^2 in the year 2000. We then calculated the live aboveground biomass for the years 1961 and 2000 in Máze and for the years 1978 and 1999 in Målselv (Tables 4.5, 4.6). The total live aboveground biomass of the birch forests increased in both study areas during this period, and is consistent with the increment of the birch forest areas in the same period (Tables 4.3–4.6). The tree biomass (as well as the growing stock) in Máze increased by more than 60 % in the period 1961–2000, but the biomass of the shrub and field layers also increased significantly. However, the biomass of lichens showed a significant reduction (70 %) in Máze from 1961 to 2000. The *Cornus-Myrtillus* birch forest (CMB) and the moss-rich *Myrtillus* birch forest (MMB) areas increased significantly from ca. 2000 to nearly 800 km^2, and these forest types also showed a significant increment in the total live aboveground biomass (Tables 4.3, 4.4).

In Målselv, forests increased less than in Máze, but, taking into consideration the significantly shorter period (20 years), the total forest area in Målselv increased from ca. 2400 km^2 in 1978 to 2800 km^2 in 1999, and the total live aboveground biomass (tree, shrub and field layers) also showed an increment in the same period (Tables 4.5, 4.6). For the lichen biomass expressed as reindeer fodder units, however, we could observe a decrease from 1978 to 1990 with a subsequent increase in the biomass from 1990 to 1999. The number of reindeer supported in the winter period (181 days) showed the same trend (Table 4.7).

In Utsjoki, northern Finland, there has been a drastic change in the biomass and productivity of mountain birch forests due to the catastrophic defoliation by *Epirrita autumnata* in the mid-1960s (Kallio and Lehtonen 1973, 1975, see also Chap. 9). Understandably, there are no remote sensing data from the period before the outbreak. However, Kukkonen (2002) studied the recovery of mountain birch forests in Utsjoki after the *E. autumnata* damage in the mid-1960s. She measured the diameters of both alive and dead (remains of the 1960s damage) birches in 156 study plots (20 × 20 m) and used the regression equation of Starr et al. (1998) to estimate the foliar biomass both in 2000 and before the 1960s outbreak, and calculated the degree of recovery as the percentage between the two. The median recovery percentage was only 5 % in 2000 (calculated from Kukkonen 2002). This highlights the great decrease in birch forest biomass in Utsjoki from the early 1960s to the present, as well as the very poor (or effectively zero at many sites) recovery under the current climate and grazing pressure.

Data for Utsjoki, Inari and Enontekiö are presented from the Nature Survey carried out by The Northern Lapland District for Wilderness Management (Sihvo 2002). The total volume of wood in the mountain birch forests was about 7.4 million m^3 (Table 4.8), which gives an average volume of only 11 m^3/ha. In the dense forests, the average volume was 26 m^3/ha.

Table 4.7. Lichen biomass expressed as reindeer fodder units in parts of Målselv during the period 1978–1999 (1 kg dry wt. lichen=0.6 RFU). The annual grazing period is 181 days

Lichen biomass and reindeer numbers	1976/1978	1990	1999
Biomass of lichens (RFU)	897,847	538,734	690,910
Number of "reindeer days"	448,923	269,367	345,455
Number of reindeer supported for 181 days	2480	1488	1909

Table 4.8. Volumes of mountain birch forests (tree volume) with different categories of degree crown coverage in Utsjoki, Inari and Enontekiö. (Data from Sihvo 2002)

Forest type	Inari		Utsjoki		Enontekiö		Total	
	Area (km^2)	Biomass in 1000 m^3	Area (km^2)	Biomass in 1000 m^3	Area (km^2)	Biomass in 1000 m^3	Area (km^2)	Biomass in 1000 m^3
Open fell heath with scattered birch trees/stands	850	176	570	57	640	84	2060	317
Sparse mountain birch forests	1170	1311	730	597	1100	1243	3000	3151
Dense mountain birch forests	710	1927	340	936	450	1028	1500	3891
Total	2730	3414	1640	1590	2190	2355	6560	7359

Field monitoring in Finnish Lapland during 1983–1999 showed increased basal areas of both pine and birch at the northernmost timberline and treeline areas (Juntunen et al. 2002). At the conifer tree line (i.e. in the mountain birch forest zone) the birch basal area increased from about 5 to7 m^2/ha during this period.

4.4 Discussion

4.4.1 Biomass Changes

The reasons for the observed changes in the extent of forests and the increase in biomass for most of the species groups and layers are not known, but the spatial patterns seen in Fig. 4.1 offer some explanations. Increased forest regrowth in northern Norway, reduction of the thick lichen layer in large areas of the continental parts of northern Fennoscandia by grazing, declining harvests of forests in the Nordic countries, improved silviculture in the Nordic countries, and woody encroachment, elevation of the timberline and longer growing seasons from warming in the northern latitudes possibly explain some of the changes (Graze et al. 2002).

Based on satellite observations, Zhou et al. (2001) and Lucht et al. (2002) concluded that there was an earlier greening trend in many districts of the high northern latitudes, associated with a gradual lengthening of the growing season, which has also been shown by additional evidence such as tree phenology trends (Menzel and Fabian 1999). Høgda et al. (2001), however, found a trend to shorter growing seasons in some, more continental parts of northern Fennoscandia, in spite of a slight general warming of the climate during the past two decades, but also an increase in the snow cover.

The trend of a gradual lengthening of the growing season and increase in biomass in many northern latitudes observed by us, Myneni et al. (2001) and Lucht et al. (2002) cannot easily be explained away as an artifact of the methods used to calibrate long satellite time series. The satellite time series was dramatically interrupted by the Pinatubo eruption, which reduced LAI while producing an increased carbon sink that contributed to the observed (and temporary) slowdown in the global rate of increased atmospheric CO_2 concentration (Keeling et al. 1996). Understanding the causes of such variability is an important step in distinguishing natural from human-induced perturbations of the Earth's ecosystems. This implies uncertainty regarding the future of biomass sinks and therefore the need for monitoring (Myneni et al. 2001).

In our study, we estimated biomass using data from other authors on mountain birch biomass (often from other regions, cf. Table 4.1), however, these results may not fit the variation in the mountain birch forests in Fennoscandia. On the other hand, the significant increase in the extent of the forests is in agreement with data from Statistics of Norway (1979) and data from the County Forest Board in Finnmark (Fylkesmannen i Finnmark 2002). For example, the mountain birch forests in Kautokeino (Máze) increased from ca. 1900 km^2 in 1957, based on estimations using aerial photographs and field inventories, to ca. 3600 km^2 in 2001 (Statistics of Norway 1979; Fylkesmannen i Finnmark 2002), which is very close to our estimate (3560 km^2). Sturm et al. (2001) reported an increasing shrub abundance in the Arctic, and this is in agreement with our results in both Máze and Målselv. In Målselv, however, some of the mountain birch forests were defoliated by caterpillars (Tømmervik et al. 2001), and the increase in the extent of birch forests may have been somewhat reduced. The plausible explanations for the increase in the extent and biomass of forests in the study areas may be increased summer temperature, higher precipitation, higher winter temperatures, grazing of the lichen biomass, elevated CO_2 and nitrogen deposition, which may contribute to the advance of the timberline in the northern forests (Grace et al. 2002). Moreover, temperature limits growth more severely than it limits photosynthesis over the temperature range 5–20 °C (Grace et al. 2002). If we assume that growth and reproduction are controlled by temperature, a rapid advance of the tree line would be predicted. Indeed, some authors (Grace et al. 2002; Lucht et al. 2002) have provided photographic evidence and remotely sensed data that suggest this is, in fact, occurring, and our results presented in Fig. 4.1 and in Tables 4.2–4.3 are in agreement with these authors. In regions inhabited by grazing animals such as Finnmark and Lapland, the advance of the timberline will be curtailed, although the growth of trees between the tree line and the timberline will, of course, increase substantially.

In Kevo, Utsjoki, Inari, and Enontekiö, the volume of the mountain birch forests has been estimated several times (Mattsson 1987; Salmi 1988; Sihvo 2002), based on field investigations and remote sensing. According to Mattsson (1987), the average volume of the mountain birch forests in Utsjoki (Kevo) was 11.9 m^3/ha and the total volume 1.703 million m^3. According to the Nature Survey (Sihvo 2002), the corresponding figures were 9.7 m^3/ha and 1.590 million m^3. The volume according to Salmi (1988) was significantly lower (211,000 m^3) in Utsjoki than the estimates carried out by the Nature Survey (Sihvo 2002), but Salmi took reasonable distances from roads and limitations of felling into consideration. If we look at the area of the mountain birch forests in Utsjoki, they increased from about 1430 km^2 in 1987 (Mattsson 1987) to about 1640 km^2 in 2000 (Sihvo 2002). However, the latter author estimated that in Utsjoki at least 600 km^2 of mountain birch forest damaged by *E. autumnata* is now treeless (see also Chap. 9), and was not included in the above forest area. Thus, the mountain birch forest area in Utsjoki in the early 1960s was over 2200 km^2. A total area of 2354 km^2 was damaged by caterpillars (*E. autumnata*) in Utsjoki, Enontekiö and Inari districts. In Kiruna

(Abisko) the area of mountain birch forests was estimated to be ca. 1600 km^2 (Riksskogtaxeringen 2001).

The changes from lichen–dwarf shrub-dominated forests to more grass- and herb-dominated forests in Máze need some comments: in forests of the dwarf shrub type, several studies have generally shown that lichens, crowberry (*Empetrum hermaphroditum*), bilberry (*Vaccinium myrtillus*) and cowberry (*Vaccinium vitis-idaea*) were declining in the face of competition from wavy hair grass (*Deschampsia fleuxuosa*) and different forbs; this has been found to be an effect of nitrogen since these species are slow-growing and adapted to nutrient-poor systems (Lipson et al. 1996; Nordin et al. 1998). Furthermore, insect and fungal attacks on bilberry may increase when the nitrogen deposition increases (Nordin et al. 1998). In Máze Tømmervik et al. (2004) found a significant correlation between the increase in the area of these forests and the increase in precipitation as well as variation of nitrogen deposition. The trampling and grazing of reindeer in the lichen-dominated birch forests of Máze during the summer season may also, in addition to precipitation and nitrogen deposition, be a causal effect on the increase and change in the forest structure. The removal of "the barrier effect" by the thick lichen coverage makes it easier for the birch seeds to sprout, and should also be taken into consideration. Another explanation could be lichen death under ice crusts due to higher winter temperatures and reduction of O_2 (Wielgolaski 2001). This has again led to an elevation of the timberline by filling in the gap between the tree line and timberline with forest (Sveinbjörnsson et al. 2002). Tømmervik et al (2004) found a significant and co-varying relationships between the number of reindeer in the area and the increase in forbs- and grass-dominated forests within this area. On the other hand, the significant increase in the sub-oceanic species *Cornus suecica*-dominated forests in the period 1961–2000 in Máze and Målselv is probably more related to the increased precipitation (cf. Chap. 17) in the same time period measured by several meteorological stations within the study area as well as in the adjacent areas. In Frihetsli in Målselv the precipitation in June–July increased by 40 %. Furthermore, the much stronger dominance of the mosses *Pleurozium schreberi* und *Hylocomium splendens* indicates a higher precipitation during summer in both study areas (Chap. 17, Bakkestuen et al. 2000).

4.4.2 Remote Sensing Data – Are They Robust?

How robust are these results? Residual atmospheric effects and calibration errors in satellite and aerial data cannot be ruled out. The accuracy of the vegetation maps used in the analysis is in the range of 75–90 % overall accuracy (Tømmervik and Lauknes 1987; Johansen and Tømmervik 1990; Tømmervik et al. 2003), and this is satisfactory compared to results from Finland (80–92 % overall accuracy; Colpaert et al. 1995). Uncertainties in inventory data and the field estimations of biomass used in this study are difficult to quantify because they differ from investigation to investigation. Simple models are used to convert wood volume and vegetation cover type data to biomass. The differences in forest area estimates between remote sensing and field inventories are not easy to reconcile because of definition issues. Detailed forest inventories for the mountain birch forests in northern Fennoscandia are only done in the most valuable and productive parts of the forests, and we have to rely on remote sensing in order to monitor these forests. Maps like the one presented in Fig. 4.1, showing the trends in NDVI in Fennoscandia in the period 1982–1999, should only be used as maps showing a trend toward environmental change and not as a source for detailed analysis and discussions. We have (so far) to trust field-based investigations, aerial photographs and medium and high resolution satellite imagery in order to monitor and analyse the changes in the forests. However, maps showing long-term trends could be of valuable help in "pin-pointing" areas undergoing large environmental changes. All of this suggests a cautionary reading of the results and need for further research. Nevertheless, the trends in the data are consistent with forest inventories in Fennoscandia and the increase and re-growth of the mountain birch forests are significant and quite interesting to follow up.

Acknowledgement This study has financially supported by Norwegian Research Council through the PhenoClim project and the 5th Framework program in EU (HIBECO project).

References

Aradottir AL, Arnolds O (2001) Ecosystem degradation and restoration of birch woodlands in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 293–306

Bakkestuen V, Stabbetorp OE, Eilertsen O, Often A, Brattbakk I (2000) Terrestrisk naturovervåking. Vegetasjonsøkologiske undersøkelser av boreal bjørkeskog i Øvre Dividal og Gutulia nasjonalparker – reanalyser 1998 (in Norwegian). (Monitoring terrestrial ecosystems: ecological investigations of vegetation in the boreal forest of Dividalen and Gutulia National Parks – reanalysis 1998.) NINA Oppdragsmelding 612:1–58

Bylund H, Nordell O (2001) Biomass proportion, production and leaf nitrogen distribution in a polycormic mountain birch stand (*Betula pubescens* ssp. *czerepanovii*) in northern Sweden. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New-York, pp 115–126

Chapin FS, Shaver GR (1996) Physiological and growth responses of arctic plants to a field experiment simulating climatic change. Ecology 77:822–840

Colpaert AJ, Kumpula J, Nieminen M (1995) Remote sensing, a tool for reindeer range land management. Polar Rec 31:235–244

Dahlberg U (2001) Quantification and classification of Scandinavian mountain vegetation based on field data and optical satellite images. Report 12–2001. Dep For Res Manag Geomat, Swedish Univ Agr Sci, Umeå, Sweden. ISBN 91–576–5581–2

Elkington TT, Jones MG (1974) Biomass and primary production of birch *Betula pubescens* s. lat.) in south-west Greenland. J Ecol 62:821–830

Fylkesmannen i Finnmark (2002) Årsmelding for skogbruket i Finnmark 2001 (in Norwegian), 24 pp

Gaare E, Tømmervik H (2000) Monitoring of lichen grazing areas in Finnmark. NINA Oppdragsmelding 638:1–33

Grace J, Berninger F, Nagy L (2002) Impacts of climate change on the tree line. Ann Bot 90:537–544

Hagner O (1990) Computer aided forest stand delineation and inventory based on satellite remote sensing, SNS/TUFRO workshop. The usability of remote sensing for forest inventory and planning, Umea, Sweden, pp 94–105

Hanssen-Bauer I, Förland E (2000) Temperature and precipitation variations in Norway 1900–1994 and their links to atmospheric circulation. Int J Climatol 20:1693–1708

Helland A (1912) Traegraendser og sommervarmen (in Norwegian). Tidsskr Skogbr 20:131–146, 169–175, 303–313

Høgda KA, Karlsen SR, Tømmervik H (2001) Onset of spring in Fennoscandia studied by a time series of NOAA AVHRR NDVI data. Poster: "The times they are a-changin'" – International Phenological Conference – Climate change, phenological responses and their consequences for biodiversity, agriculture, forestry, and human health, 5–7 Dec 2001, Wageningen University, the Netherlands

Johansen B, Tømmervik H (1990) Mapping winter grazing areas for reindeer in Finnmark county, northern Norway, using LANDSAT 5-TM data. IGARSS-90 Proceedings, Washington DC, 4 pp

Johansen B, Karlsen SR (1996) Reingjerder i Finnmark – virkning på flora, vegetasjon og endringer av vegetasjonsdekket (in Norwegian). Sluttrapport – NORUT IT, Tromsö, Norway, 123 pp

Johansen B, Karlsen SR (2000) Finnmarksvidda – kartlegging og overvåking av reinbeiter – status 1998 (in Norwegian). NORUT IT 546/1–00, 68 pp

Johansson T (1999) Biomass equations for determining fractions of pendula and pubescent birches growing on abandoned farmland and some practical applications. Biomass Bioenergy 16:223–238

Jonasson S, Lee JA, Callaghan TV, Havstrom M, Parsons AN (1996) Direct and indirect effects of increasing temperatures on subarctic ecosystems. Ecol Bull 45:180–191

Juntunen V, Neuvonen S, Norokorpi Y, Tasanen T (2002) Potential for timberline advance in northern Finland, as revealed by monitoring during 1983–1999. Arctic 55:348–361

Kallio P, Lehtonen J (1973) Birch forest damage caused by *Oporinia autumnata* (Bkh.) in 1965–1966 in Utsjoki, N-Finland. Rep Kevo Subarctic Res Stat 10:55–69

Kallio P, Lehtonen J (1975) On the ecocatastrophe of birch forests caused by *Oporinia autumnata* (Bkh.) and the problem of reforestation. In: Wielgolaski FE (ed) Fennoscandian tundra ecosystems, part 2. Animals and systems analysis. Springer, Berlin Heidelberg New York, pp 174–180

Keeling CD, Chin FS, Whorf TP (1996) Increased activity of northern vegetation inferred from atmospheric CO_2 measurements. Nature 382:146–149

Kjelvik S, Kärenlampi L (1975) Plant biomass and primary production of Fennscandian subarctic and subalpine forests and of alpine willow and heath ecosystems. In: Wielgolaski FE (ed) Fennoscandian tundra ecosystems, part 1. Plants and microorganisms. Springer, Berlin Heidelberg New York, pp 111–120

Korsmo H (1995) Weight equations for determining biomass fractions of young hardwoods from natural regenerated stands. Scand J For Res 10:333–346

Kukkonen T (2002) Tunturikoivikoiden elpyminen tunturimittarin aiheuttamista tuhoista Kevon luonnonpuistossa (in Finnish). MS Thesis, Turun yliopisto, Finland. Maantiteen laitos, 131 pp + 3 App

Lipson DA, Bowman WD, Monson RK (1996) Luxury uptake and storage of nitrogen in the rhizomatous alpine herb, *Bistorta bistortoides.* Ecology 77:1277–1285

Lucht W, Prentice IC, Myneni RB, Sitch S, Friedlingstein P, Cramer W, Bousquet P, Buermann W, Smith B (2002) Climatic control of the high-latitude vegetation greening trend and Pinatubo effect. Science 296:1687–1689

Lyftingsmo E (1965) Norske fjellbeite Bind XV Oversyn over Fjellbeite i Finnmark (in Norwegian). Kgl Selsk Norges Vel, Oslo, Norway, 367 pp

Marklund LG (1988) Biomassafunktioner för tall, gran och björk i Sverige (in Swedish). Work Rep 45. Dept For Res Manag Geomatics, Swedish Univ Agr Sci, Umeå, Sweden

Mattsson J (1987) Ihmisen vaikutus Utsjoen metsärajametsiin (in Finnish). MS Thesis, Turun yliopisto, Finland. Maantiteen laitos, 123 pp

Menzel A, Fabian P (1999) Growing season extended in Europe. Nature 397:659

Myneni RB, Keeling, CD, Tucker CJ, Asrar G, Nemani RR (1997) Increased plant growth in the northern high latitudes from 1981 to 1991. Nature 386:698–702

Myneni RB, Dong J, Tucker CJ, Kaufmann RK, Kauppi PE, Liski, J, Zhou L, Alexeyev V, Hughes MK (2001) A large carbon sink in the woody biomass of Northern forests. Proc Natl Acad Sci USA 98:14784–14789

Nordin A, Nasholm T, Ericson L (1998) Effects of simulated N deposition on understorey vegetation of a boreal coniferous forest. Funct Ecol 12:691–699

Odland A (1996) Differences in the vertical distribution pattern of *Betula pubescens* in Norway and its ecological significance. In: Frenzel B (ed) Holocene treeline oscillations, dendrochronology and paleoclimate. Fisher, Stuttgart, pp 43–59

Post E, Stenseth NC (1999) Climatic variability, plant phenology, and northern ungulates. Ecology 80:1322–1339

Raitio H, Paukkonen K, Kauppi A (1994) Effects of defoliation, nitrogen, and temperature on leafing and root carbohydrates of birch seedlings. Can J For Res 24:1914–1920

Reese H, Nilsson M (1999) Using Landsat TM and NF data to estimate wood volume, tree biomass and stand age in Dalarna. Work Rep 53. Dept For Res Manag Geomatics, Swedish Univ Agr Sci, Umeå, Sweden

Riksskogstaxeringen (2001) Forest inventory statistics for Norrbotten län (Tabular data in Excel format)

Robinson CH, Wookey PA, Lee JA, Callaghan TV, Press MC (1998) Plant community responses to simulated environmental change at a high arctic polar semi-desert. Ecology 79:856–866

Salmi O (1988) Tunturikoivun polttopuukäytön lisäämismahdollisuudet Enontekiön ja Utsjoen kunnissa. Maataloushallinnon aikakauskirja. Maatilahallituksne julkaisu 2:12–16. Valtion painatuskeskus/Helsingin paino Oy, Finland (in Finnish)

Senn J, Haukioja E (1994) Reactions of the mountain birch to bud removal – effects of severity and timing, and implications for herbivores. Funct Ecol 8:494–501

Senn J, Hanhimaki S, Haukioja E (1992) Among tree variation in leaf phenology and morphology and its correlation with insect performance in the mountain birch. Oikos 63:215–222

Sihvo J (2002) Ylä-Lapin luonnonhoitoalueen ja Urho Kekkosen kansallispuiston luontokartoitus. Loppuraportti osa 2: Ylä-Lapin luontotyypit. Metsähallituksen luonnonsuojelujulkaisuja. Sarja A137, 175 pp, Helsinki (in Finnish)

Ståhl G, Walheim M, Lofgren P (1999) Fjällinventering – En utredning av innehall och design (in Swedish). Work Rep 50. Dept Res Manage Geomatics, Swedish Univ Agr Sci, Umeå, Sweden

Starr M, Hartman M, Kinnunen T (1998) Biomass functions for mountain birch in the Vuoskojarvi integrated monitoring area. Boreal Environ Res 3:297–303

Statistics of Norway (1979) Landbrukstelling 1979 Skogbruk, Finnmark and Troms (in Norwegian). Census of agriculture and forestry, vol VII. Forestry

Steininger MK (2000) Satellite estimation of tropical secondary forest above-ground biomass: data from Brazil and Bolivia. J Remote Sensing 21:1139–1158

Sturm M, Racine C, Tape K (2001) Climate change: increasing shrub abundance in the Arctic. Nature 411:546–547

Sveinbjörnsson B (1987) Biomass proportioning as related to plant size in juvenile mountain birch near Abisko, Swedish Lapland. Rep Kevo Subarctic Res Stat 20:1–8

Sveinbjörnsson B , Hofgaard A, Loyd A (2002) Natural causes of the Tundra-Taiga boundary. Ambio Spec Rep 12: 23–29

Tømmervik H (2000) Reinbeitekartlegging Mauken-Blåtind-Fagerfjell (in Norwegian). NINA Assignment Rep 641:1–34

Tømmervik H, Lauknes I (1987) Mapping of reindeer ranges in the Kautokeino area, northern Norway, by use of Landsat 5/TM data. Rangifer 2:2–14

Tømmervik H, Johansen B, Lauknes I (1997) Use of airborne CASI spatial mode data for mapping of Sub-Arctic mountain heaths in Pasvik, northern Norway. Can J Remote Sensing 23:230–242

Tømmervik H, Johansen ME, Pedersen JP, Guneriussen T (1998) Integration of remote sensed and in-situ data in an analysis of the air pollution effects on terrestrial ecosystems in border areas between Norway and Russia. Environ Monit Assess 49:51–85

Tømmervik H, Høgda KA, Karlsen SR (2001) Using remote sensing for detection of caterpillar outbreaks in mountain birch forests, a new interesting approach. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 185–194

Tømmervik H, Høgda KA, Solheim I (2003) Monitoring vegetation changes in Pasvik (Norway) and Pechenga in Kola Peninsula (Russia) using multi-temporal Landsat MSS/TM data. Remote Sensing Environ 85:370–388

Tømmervik H, Johansen B, Tombre I, Thannheiser D, Högda KA, Gaare E, Wielgolaski FE (2004) Vegetation changes in the Nordic mountain birch forest: the influence of grazing and climate change. Arct Antarct Alpine Res 36:322–331

Väre H (2001). Mountain birch taxonomy and floristics of mountain birch woodlands. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, London, pp 35–46

Vaarama A, Valanne T (1973) On the taxonomy, biology and origin of *Betula tortuosa* Lebeb. Rep Kevo Subarctic Res Stat 10:70–84

Wang TL, Tigerstedt PMA (1996) Growth rates and phenology of fast- and slow-growing families over an entire growth period in *Betula pendula* Roth. Silvae Genet 45:124–129

Wang JR, Zhong AL, Simard SW, Kimmins JP (1996) Aboveground biomass and nutrient accumulation in an age sequence of paper birch (*Betula* x *pyrifera*) in the Interior Cedar Hemlock zone, British Colombia. For Ecol Manage 83:27–38

Wielgolaski FE (2001) Field-and bottom layer vegetation mat transplantation. A method to simulate possible effects of climate change. Skogræktarritid 1:167–170

Wielgolaski FE, Bliss, LC, Svoboda I, Doyle G (1981) Primary production of tundra. In: Bliss LC, Heal OW, Moore JJ (eds) Tundra ecosystems: a comparative analysis. IBP 25. Cambridge Univ Press Cambridge, pp 187–225

Zhou L, Tucker CJ, Kaufmann RK, Slayback D, Shabanov NV, Myneni RB (2001) Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. J Geophys Res 106(D17):20069–20083

5 Mountain Birch Growth in Relation to Climate and Herbivores

P.S. Karlsson, M. Weih and C. Borg

5.1 Introduction

Plants growing at high latitudes or altitudes are often considered to be well adapted to low temperatures; nevertheless, the short growing season and low temperatures can be expected to be important factors limiting growth in such environments (Chapin 1983). Several other factors, such as nutrient availability and herbivory, are potentially also important. Photosynthesis is the primary process behind biomass production and has consequently been the focus of many studies of primary productivity. Growth rate, however, is often determined by leaf area per unit biomass rather than by photosynthesis rate (Körner 1991). Accordingly, comparison of the effects of temperature on mountain birch photosynthesis (Sveinbjörnsson 1983) and growth (Karlsson and Nordell 1996) indicates poor agreement between the photosynthetic response and the growth response. Several previous papers on mountain birch growth ecophysiology have focused on the role of nutrients, mainly nitrogen (e.g. Sveinbjörnsson et al. 1992; Karlsson and Weih 1996; Weih 1998a). Here, we will review the effects of temperature, climate and herbivores on birch establishment and productivity. We will also address some potential effects of a changing climate on the growth of mountain birch forests. Since growth performance at different life stages of this tree is partly determined by different factors, three different stages will be discussed separately, viz., seedlings, saplings and mature trees. Seedlings are defined as plants that have emerged from seeds, are ≤5 years old and have a height up to 0.3 m; saplings may have emerged from seeds or may be basal sprouts from polycormic trees and have a height of 0.3–2 m; all plants ≥ ca. 2 m are called mature trees.

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

5.2 Seedling Establishment and Growth

Seedlings lack the extensive storage capacity for resources (e.g. carbon and mineral nutrients) found in mature trees. Furthermore, birch seedlings lack the "pool" of basal dormant buds that are common on older birches (Kauppi 1989). Therefore, growth and survival of seedlings are more sensitive to rapid changes in the environment, or large perturbations, than mature trees. Hence, seedling growth responses to environmental change commonly are immediate and direct when compared to mature trees, although seedling responses can be delayed due to the relatively slow response of meristem dynamics at this stage (Weih 2000a).

In terms of mountain birch colonisation and distribution, the seedling stage is one of the most critical life history stages for this tree (Sveinbjörnsson 2000). Thus, it has been shown that successful establishment of mountain birch individuals predominantly occurs in certain years, presumably warm years with favourable conditions for seedling performance (Sonesson and Hoogesteger 1983). At a given site, the frequency of years with a favourable climate for seedling establishment, in proportion to the average life length of adult trees, will determine the establishment and survival of a forest. Events with catastrophic mountain birch dieback after severe outbreaks of herbivorous insects show that re-colonisation of disturbed sites do not always occur (cf. below and Chap. 12). This lack of colonisation success may be due to difficulties for seeds to germinate and seedlings to become established, but also to herbivory damage on small seedlings and saplings.

5.2.1 Abiotic and Biotic Environment During the Growing Season

Under the climatic conditions in subarctic regions, young birch seedlings often do not grow more than a few millimetres in height during one growing season and the relative growth rate of mountain birch seedlings grown in disturbed field sites in northern Sweden was between 2 and 3 % per day (Weih and Karlsson 1999a). The availability of nutrients, particularly nitrogen, is the most limiting factor for mountain birch seedling growth during July and August, whereas temperature seems to be more important than nutrients at the beginning of the growing season in June (Karlsson and Nordell 1989; Karlsson and Weih 1996; Weih and Karlsson 1997). The initially strong and direct effect of temperature on seedling growth is probably related to a strong temperature effect on phenology and leaf expansion rate early in the growing season (e.g. Junttila and Nilsen 1993; Karlsson et al. 2003; see also below). Furthermore, temperature also indirectly affects seedling growth rate later in the growing season, partly through a great influence of soil temperature on root nitrogen uptake rate (Karlsson and Nordell 1996), partly through an effect of

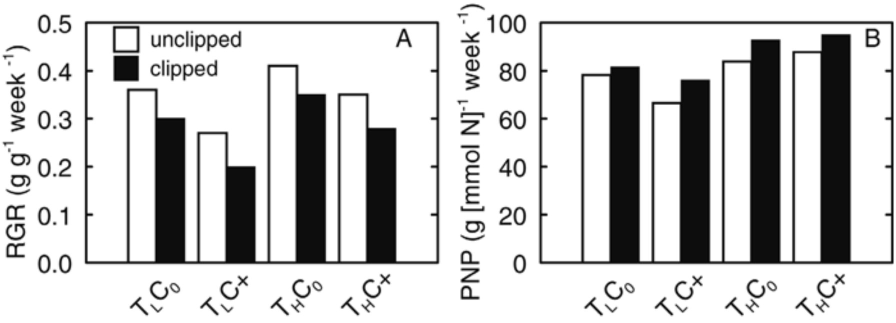


Fig. 5.1. **A** Mean relative growth rate (*RGR*) and **B** nitrogen productivity (*PNP*) of first-year mountain birch seedlings. The plants were pot-grown outdoors for 10 weeks during one growing season in northern Sweden. All individual leaves of seedlings in the clipped treatment were cut in half in early July in order to simulate an attack of leaf herbivores. T_L Temperature low (ambient) and T_H high (mean 2.1 °C above ambient); $C+$ with and C_0 without a competing neighbour seedling in the same pot. All seedlings were fertilised weekly with complete fertiliser solution corresponding to 8 g N m^{-2} per season and mean soil temperature in the T_L treatment was 9.3 °C. Treatments, sampling and analysis were carried out in a similar way as described by Weih and Karlsson (1999a)

air temperature on leaf nitrogen concentration and partly through nitrogen productivity that is sensitive to both air and soil temperature (Weih and Karlsson 2001a; Fig. 5.1). Since a fast growth rate of seedlings during the first growing season is crucial for survival in the following winter, soil temperature is strongly related to winter survival and greatly influences the success of seedling establishment (Weih and Karlsson 1999a; Karlsson and Weih 2001). Therefore, the colonisation of new habitats by mountain birch seedlings in the cold and often nutrient-poor environments of the subarctic is generally a rare event and restricted to disturbed sites and early-successional patches, where competition is reduced and soil temperature is enhanced due to a sparse vegetation cover (Weih 2000b). Specifically, the particular combination of a given soil temperature with the soil nutrient supply rate to seedlings will determine mountain birch seedling survival of the first winter, and high soil temperature can, to a certain amount, compensate for low soil nutrient availability (Weih and Karlsson 1999a).

In addition to the abiotic environment, mountain birch seedling growth and nitrogen economy are also strongly affected by factors related to the biotic environment, such as the presence and type of neighbouring plants and the effects of leaf removal by herbivorous insects (cf. Fig. 5.1). The effects of neighbouring plants on seedling growth and survival can be explained partly in terms of a change in the abiotic environment such as shading and its influence on soil temperature, and partly by means of resource competition and/or allelopathy (Weih and Karlsson 1999a). The removal of leaf biomass by herbivores early in the growing season, as simulated by an experimental clipping treatment, resulted in decreased relative growth rate, but increased nitrogen productivity during the following main growing season (cf. Fig. 5.1). Thus, the leaf removal caused a great resource loss and a drop in biomass production, which however was partly compensated for by increased efficiency in the utilisation of the remaining nutrient resources.

5.2.2 Winter Conditions

From the perspective of a seedling, the most important environmental factor during winter is probably soil temperature, which in turn is a function of snow depth. Seedlings apparently take up a significant amount of nitrogen during late autumn and early winter as long as soil temperature is not too low (Weih and Karlsson 1997; Weih 2000b). Thus, soil temperature in late autumn and early winter will affect seedling nutrient status and, consequently, growth during the subsequent early growing season. Moreover, decreased snow depth and winter soil temperature have been shown to reduce the amount of plant-available soil nitrogen (Brooks et al. 1998; Weih 1998b), which could further influence seedling growth during the subsequent growing season. In addition to the direct effects of winter temperature on seedling nutrient limitation, low soil temperature during winter can result in strong root injury. Such injury stimulates the production of new roots to replace dead roots, reduces nutrient uptake capacity and growth rate of mountain birch seedlings during the following summer (Weih and Karlsson 2002). In concert with other factors that may cause root damage during winter, e.g. frequent freeze–thaw cycles, the mechanism proposed by Weih and Karlsson (2002) could be important for growth and survival of mountain birch seedlings and supports the general conclusion by Sveinbjörnsson (2000) that the combination of resource limitation and increased environmental hazard could be seen as complementary determinants of mountain birch distribution.

5.2.3 Genetic Aspects

There is large intraspecific variation within the mountain birch. This is partly a general phenomenon for birch species (Eriksson and Jonsson 1986), which probably is enhanced in the mountain birch due to introgression with *B. nana* (Thórsson et al. 2001). The specific genetic constitution strongly influences the pattern of seedling response to environmental conditions (Weih and Karlsson 2001b). For example, growth responses of mountain birch seedlings to changes in temperature, fertilisation and UV radiation vary between provenances, ecotypes and individuals of mountain birch (genotype × environment interaction effects; Weih et al. 1998a, b; Weih and Karlsson 1999b). The genotype × environment interaction effects were found with regard to various growth traits and suggest that different physiological types of mountain birch (i.e. provenances, ecotypes and individuals) are adapted to different types of environments. For example, there is evidence from mountain birch that the general pattern of increasing leaf nitrogen content with altitude (e.g. Körner 1989) partly is genetically determined and associated with enhanced growth rate under a cool climate, but reduced growth rate stimulation with an increase in temperature (Weih and Karlsson 1999b, 2001a).

5.3 Sapling Growth

Saplings may emerge from seeds and are then, at least initially, monocormic, while saplings originating from basal sprouts lack a seedling stage and by definition are parts of old trees that have several stems (i.e. are polycormic). These differences have consequences for the growth pattern of these two types of saplings.

Growth of monocormic saplings of seed origin was monitored in the vicinity of the Abisko station (P.S. Karlsson, unpubl.) over a 10-year period and showed very low height growth (ca. 2 % year^{-1}), i.e. over the entire 10-year period the mean height increased by 22 %. No relationships between sapling annual height growth and climate were found. On average, a sapling showed positive growth only every second year (+6.2 cm), while height growth was zero in 23 % of the years and negative during 27 % (–4.2 cm). Bite marks were usually found on saplings that decreased in size and negative growth was in most cases caused by winter herbivory by hares (*Lepus timidus*) and moose (*Alces alces*; P.S. Karlsson, pers. observ.). Fertilised saplings showed no significant net growth (relative growth rate 0.6 % year^{-1}) over the same period and thus performed worse than control saplings, due to a greater attractiveness to herbivores compared to unfertilised controls. Thus, when exposed to natural winter herbivory, the height reduction was largest for fertilised plants.

Stems emerging as basal sprouts from polycormic trees showed a fundamentally different growth pattern to the monocormic saplings (Fig. 5.2). Initially, they had more than a 100-fold higher growth rate compared to the monocormic saplings (>2 versus 0.02). The growth performance of basal sprouts depends on the conditions when they emerge. Saplings originating during or shortly after a large *Epirrita* outbreak, causing mortality among the old stems, have a slightly faster growth rate than those emerging under undisturbed conditions; over their first 10 years these saplings had an average annual growth rate (RGR) of 0.61 and 0.57 respectively. The difference in RGR between *Epirrita* outbreak triggered sprouts and sprouts emerging after other periods may appear small, nevertheless, the accumulated biomass after 10 years is almost three-fold larger for the saplings emerging after an *Epirrita*

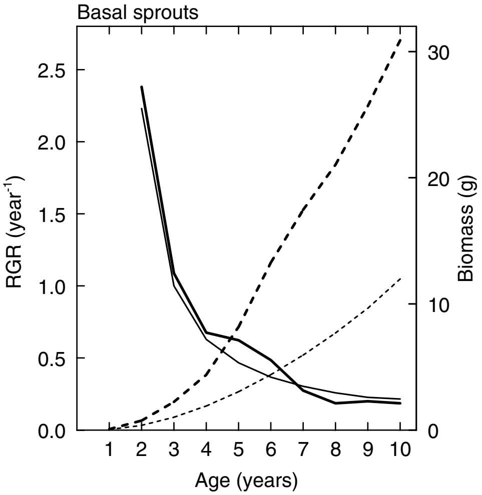


Fig 5.2. Growth of saplings originating from basal sprouts of polycormic mountain birch trees. Growth was calculated from annual tree-ring widths using the basal diameter–biomass relationship by Bylund and Nordell (2001). *Solid lines* indicate relative growth rate (RGR) and *broken lines* biomass, *thick lines* indicate performance of sprouts emerging after a severe *Epirrita* outbreak resulting in high stem mortality (cf. Tenow and Bylund 2000; Tenow et al. 2004) and *thin lines* growth of sprouts emerging under undisturbed conditions

outbreak (cf. Fig. 5.2). The very high initial growth rate is probably achieved through a relatively good supply of growth resources from the old parts of the tree. They also show higher leaf nitrogen contents and higher photosynthetic capacity than seedlings (Kauppi et al. 1990).

5.4 Mature Trees

Growth performance of mature mountain birch trees in situ has been studied by three different approaches: (1) studies of shoot growth and shoot population dynamics, (2) biomass harvests and (3) annual tree ring growth. Studies at the shoot level have been performed mainly in relation to responses to herbivory and costs of reproduction (e.g. Haukioja et al. 1990; Lehtilä et al. 1994; Karlsson et al. 1996; Henrikson et al. 1999; Chap. 12). Here, we focus on biomass harvest and tree ring methods.

5.4.1 Tree Growth and Climate

For the mountain birch, biomass of various aboveground compartments is closely correlated to stem diameter (Starr et al. 1998; Bylund and Nordell 2001; Dahlberg 2001), stem height (Sveinbjörnsson 1987) or a combination of both (Kjelvik 1971). Basal stem diameter and annual stem width increments, i.e. tree-ring widths, thus give good estimates of tree biomass and growth. Based on the biomass equations presented by Bylund and Nordell (2001) and a tree-ring series from the Abisko valley (Tenow et al. 2004), the aboveground relative growth rate (RGR) of mature mountain birch trees was estimated at 10 % per year at an age of 25–30 years, and 5 and 2 % per year in 50- and 100-year-old trees respectively.

Deviations from the tree-ring width–biomass relationship may occur during certain years and during outbreaks of defoliating insects (cf., Eckstein et al. 1991; Hoogesteger and Karlsson 1992; Karlsson et al. 2001). In order to relate ring widths and whole tree growth to climatic conditions, a ring series from the Abisko valley (the mean of the two series described in Tenow et al. 2004) was used to relate ring widths and whole tree growth to climatic conditions. The analysis is based on the years 1958–1988 when no large effects of *Epirrita* defoliation on growth could be expected. Using a "Hugershoff" function (Warren 1980), the age of a respective ring explained 51 % of the variation in mean ring series. The effects of climate were evaluated using age-corrected and normalised ring widths and a stepwise multiple regression approach. Various thermal time summations, monthly mean temperature and monthly precipitation were compared to interannual variations in growth. The analysis indicated that thermal time (TT, degree days above +5 °C) from the average date of budburst to late July (Julian day 156–200, cf. Karlsson et al. 2003) was the most important followed by mean May and January temperatures. The obtained regression equation was thus:

$$\text{Relative ring width} = -1.523 + 0.00440\ \text{TT} + 0.088\ T_{\text{MAY}} - 0.30\ T_{\text{JAN}} \qquad (5.1)$$

With this function 60 % of the variation in the age-corrected ring series could be related to climate. In total, 80 % of the variation in the mean tree-ring series could be explained by age and temperature. July is the month when most of the ring formation occurs (Gellinek 1997), which likely is the proximate reason for a strong relationship between ring width and temperature between bud burst and mid-July. During May, trees are usually leafless, but May temperatures are important for the date of bud burst (Karlsson et al. 2003) and thus the length of the period during which the trees have green leaves.

5.4.2 Effects of *Epirrita* Defoliation on Tree Growth

A characteristic feature of the Fennoscandian mountain birch ecosystem is the regular occurrence of population peaks of two moth species (*Epirria autumnata* and *Operophtera brumata*; e.g. Tenow 1972; Kallio and Lehtonen 1973; Chaps. 9 and 12). The *Epirrita* peaks occur at ca. 10-year intervals. During most peaks, the defoliation levels are relatively small (less than 15 %; Bylund 1995), but occasionally this moth reaches outbreak densities resulting in massive defoliation over one or several years (e.g. Tenow 1972). Mountain birch defoliation is often followed by growth reductions as indicated by reduced tree-ring widths (Eckstein et al. 1991; Hoogesteger and Karlsson 1992). An experimental 100 % defoliation resulted in strongly reduced wood production (ring widths 15–25 % of normal) over at least 4 years following defoliation (Hoogesteger and Karlsson 1992). Experimental defoliation removing 50 % of the foliage did not result in any significant reduction in ring width. In contrast, severe defoliation (ca. 93 % leaf area reduction) by *Epirrita* in situ results in a considerably smaller reduction in ring widths over 4 years (55 % of normal), and after a slightly lower defoliation level (ca. 84 %), rings were reduced in 1 year only (Fig 5.3; Karlsson and Weih 2004). There is either a very rapid change in plant response to defoliation in the interval 80–100 % or experimental defoliation results in stronger ring width reduction than natural defoliation. There could be several reasons for different responses after experimental and natural defoliations. For example, natural defoliation occurs successively during 3–4 weeks (H. Bylund, pers. comm.), while experimental defoliation usually is performed in a few hours or days. This could result in more severe consequences of experimental than natural defoliation. After severe defoliation events entire stems may die. Thus, when analysing ring-widths of stems some years after an outbreak, the data may be biased if some of the stems have died. Since the surviving stems presumably are mostly the least strongly defoliated ones, a retrospective analysis of ring widths of surviving stems may not be representative of the entire stem population present at a severe outbreak.

Epirrita peaks with high defoliation levels result in increased stem mortality followed by a sprout production in polycormic individuals (Tenow et al. 2004; Chap. 12). In extreme cases, massive tree death may occur over large areas of birch forest (Kallio and Lehtonen 1975). When stems die, death is

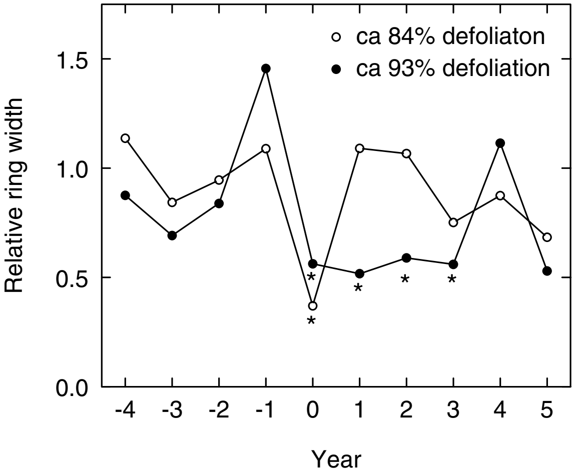


Fig 5.3. Effects of *Epirrita autumnata* defoliation on radial stem growth of mountain birch trees at two sites with different degrees of defoliation. The ring series are normalised with respect to climate to show a mean of 1.0 when unaffected by *Epirrita*. *Year 0* is when the *Epirrita* population peaked. * indicates ring widths significantly different from 1. (Modified from Karlsson and Weih 2004)

probably caused by a combination of *Epirrita* damage, subsequent attacks by larvae of the beetle *Hylecoetus dermastoides*, root rot and fungal infections (Lehtonen and Heikkinen 1995; Chap. 12). The recovery of mountain birch forests from severe *Epirrita* attacks can take many years. In one example where most tree individuals survived the outbreak, Tenow and Bylund (2000) found that a full forest recovery after the 1954–1955 outbreak would require at least 70 years. In another case, Lehtonen and Heikkinen (1995) found an initially good recovery through the establishment of seedlings, but these were negatively affected by reindeer grazing. Basal sprouts were less affected by grazing, but were disturbed by rot. Thus, 35 years after a severe outbreak in 1965, most study areas still had a greatly reduced tree density.

5.5 Forest Structure, Stand Biomass and Productivity

Polycormic trees dominate the dry, nutrient-poor heath forests, while monocormic trees dominate meadow forests and high altitudes (Kallio and Mäkinen 1978; Verwijst 1988). The number of genets per hectare in the Abisko area is 740–1200 (Tenow and Bylund 2000; Bylund and Nordell 2001). Each polycormic individual has up to 33 stems (mean stem number is 10.1; Bylund and Nordell 2001). However, most of these stems are very small, more than 50 % of all stems are below 30 mm in diameter and thus contribute marginally to the forest biomass. Correspondingly, the largest, 23 % of the stem population, make up more than 90 % of the birch biomass. Although the old stems have much lower growth rates than young ones (see above), the old stems are responsible for most of the annual biomass production. Estimating growth from biomass–stem diameter equations (Bylund and Nordell 2001) indicates that a 50-year old stem with a growth rate of 4 % has a ca. 25-fold larger annual biomass production than a 5-year old stem with a growth rate of 65 % per year.

There is relatively little information available on stand level biomass and productivity of the mountain birch (Table 5.1). The low number of sites with biomass and productivity estimates makes generalisations with respect to regional or edaphic gradients difficult. For example, both the largest and smallest biomass estimates originate from the Abisko area, northern Sweden (Table 5.1; see however, Chap. 4). Estimates of mountain birch biomass range between 10 and 35 t ha^{-1}. A higher estimate is reported from southern Greenland (48 t ha^{-1}). Similarly, annual production shows at least a two-fold variation, from 1.4 to 2.2 t ha^{-1} $year^{-1}$ (Table 5.1). These figures are considerably lower than standing biomass values and productivities of more southern forests. For example, the annual wood production of *B. pubescens* in northern Finland is 40 % of that in southern Finland (Kellomäki and Kolström 1994), and temperate broad-leaved forests have an average annual production of 8–10 t ha^{-1} $year^{-1}$ (Kira 1975).

Table 5.1. Birch aboveground biomass and production characteristics for some Fennoscandian mountain birch forests

Area	Biomass (tonnes ha^{-1})	Growth (tonnes ha^{-1} year^{-1})	Leaf area index	Source
N-W Finland		Wood: 0.2–0.5[a]		Mikkola (1986)
Vuoskojärvi, Finland	21.2			Starr et al. (1998)
Kevo, Finland	11.0	1.7	0.75[b]	Kallio (1975); Haukioja and Koponen (1975)[c]
Abisko, Sweden	27.5		2.1	Dahlberg (2001)
Abisko, Sweden, heath forest	9.6	1.4 Wood: 0.4	1.4	Zenow and Bylund (2000); Bylund and Nordell (2001)
Hardangervidda, Norway	23.1	1.5–2.2 Wood: 0.5–0.7		Kjelvik (1973)
Greenland	48.4	2.0	1.6	Elkington and Jones (1974)

[a] Estimated from wood volume growth (0.35–0.83 m^3 ha^{-1} year^{-1}) assuming a mass of 565 kg m^{-3}, the lower value is from a heath forest type while the higher value is from meadow forests

[b] Calculated from leaf mass per unit ground area assuming a leaf mass/area ratio of 80 g m^{-2}

[c] Citing Kallio and Kärenlampi (pers. comm.) for birch forest productivity

5.6 Effects of Changing Climate on Mountain Birch Growth

5.6.1 Empirical Evidence

Evidence of a recent increase in the altitude of the tree line in response to a warmer climate has been found in the southern parts of the Scandinavian mountain range (Kullman 2002; see also Chap. 1). To evaluate growth responses to increased temperature there are only short-term experiments on seedlings and year-to-year variation in tree-rings to illustrate birch responses. The mountain birch show marked growth enhancements from increased summer temperature (see above). Similarly, interannual variations in summer temperatures are reflected in tree-ring widths of the mountain birch (Kuivinen and Lawson 1982; Eckstein et al. 1991 and above). However, it is unclear if such short-term effects can be extrapolated to a generally warmer climate (cf. Strömgren and Linder 2002). The short-term response is the combination of a direct temperature effect on growth processes, increased soil decomposition and an enhanced nutrient uptake (cf. Karlsson and Nordell 1996). It is possible that soil nutrient pools eventually become depleted under a warmer climate, in this case nutrient availability will only be increased during a limited period (cf. Oechel et al. 1994).

During winter, increased snow depth will enhance seedling growth and survival, due to the positive effects on winter soil temperature and, consequently, nutrient status of the seedlings (Weih 2000b). In contrast, decreased snow depth and soil temperature during winter could have adverse effects on the root system and, consequently, nutrient accumulation rate, growth and survival of the seedlings (Weih and Karlsson 2002). In addition, high winter temperatures result in higher respiratory losses and pot-grown birches grown at low altitude (50 m) lost more of their root carbohydrate reserves than the same provenances grown at higher a latitude (450 m; Skre 1993; Chap. 6). The analysis of mountain birch annual rings from the Abisko area showed a negative relationship between ring width and January temperature (see Eq. 5.1 above). Poor growth after a warm winter could be related to the higher consumption of carbohydrate reserves observed by Skre (1993; see also Chap. 6).

Moderately increased ultraviolet radiation, caused by a reduction of the atmospheric ozone layer, generally does not appear to have a strong negative impact on mountain birch seedling growth, although particularly sensitive genotypes are expected to respond to reduced growth rate (Weih et al. 1998b). An increasing CO_2 level in the air is not expected to result in increasing growth of northern forests (Körner 2003; but cf. Chap. 6).

5.6.2 Model Predictions

According to model simulations, substantial parts of the Fennoscandian tundra areas will be colonised by forests in the future; however, model predictions vary depending on their basic assumptions (Skre et al. 2001; cf. also Chaps. 4, 20, 21). By modelling tree growth in southern and northern Finland, Kellomäki and Kolström (1994) predicted that a temperature rise of 4.1 °C will result in a two- to three-fold increase in wood production in northern Finland, but only 5–7 % increase in the south. When using the relationships between tree-ring width and climate (see Eq. 5.1 above) in combination with the relationship between stem diameter and biomass (Bylund and Nordell 2001), we obtained an estimated growth increase from increasing temperature very similar to that of Kellomäki and Kolström (1994). Our estimates are based on the assumption that the effects of climate on year-to-year variation in ring widths can be extrapolated to a situation with consistently higher temperatures.

These models commonly only take a few plant and climatic parameters into account. However, as climate changes, a series of responses may occur. Regarding the mountain birch ecosystem, changes may occur in terms of relative phenology of the mountain birch and its main herbivores as well as between the herbivores and their enemies (Bylund 1999); new herbivores may invade this system (Tenow et al. 1999), tree defence chemistry may change (Lindroth 1996) and changes in the frequency of extreme temperatures during winter and spring may affect both the birch and its herbivores (Hänninen 1996; Tenow 1966; Neuvonen et al. 1999).

5.7 Conclusions

Mountain birch growth and productivity in relation to climate and genotype have been well studied at the seedling stage under experimental conditions, but we have less knowledge of the growth performance in situ of all age classes as well as whole stands. This lack of knowledge is probably related to the low economic value of this slow-growing tree. It is, however, clear that interannual variation in growth performance is correlated to the temperature climate. Furthermore, the autumnal moth *Epirrita autumnata* has a profound effect on the mountain birch forests, both for short-term productivity and long-term dynamics. From a birch productivity perspective, the ability to produce basal sprouts in particular seems to be an important characteristic enabling these forests to grow relatively fast and to recover from severe insect outbreaks (cf. Chap. 12).

Acknowledgements. Helena Bylund was helpful in finding information in the literature.

References

Brooks PD, Williams MW, Schmidt SK (1998) Inorganic nitrogen and microbial biomass dynamics before and during spring snowmelt. Biogeochemistry 43:1–15

Bylund H (1995) Long-term interactions between the autumnal moth and mountain birch: the role of resources, competitors, natural enemies, and weather. PhD Thesis, Swedish University Agricultural Sciences

Bylund H (1999) Climate and the population dynamics of two insect outbreak species in the north. Ecol Bull 47:54–62

Bylund H, Nordell KO (2001) Biomass proportions, production and leaf nitrogen distribution in a polycormic mountain birch stand (*Betula pubescens* ssp. *czerepanovii*) in northern Sweden. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and the biosphere series, vol 27. UNESCO, Paris and Parthenon, New York, London, pp 115–126

Chapin FS III (1983) Direct and indirect effects of temperature on arctic plants. Polar Biol 2:47–52

Dahlberg U (2001) Quantification and classification of Scandinavian mountain vegetation based on field data and optical satellite images. Dept For Res Manage Geomatics, Swedish Univ Agr Sci, Rep 12

Eckstein D, Hoogesteger J, Holmes RL (1991) Insect-related differences in growth of birch and pine at northern treeline in Swedish Lapland. Holarct Ecol 14:18–23

Elkington TT, Jones MG (1974) Biomass and primary production of birch (*Betula pubescens* s. lat.) in south-west Greenland. J Ecol 62:821–830

Eriksson G, Jonsson A (1986) A review of the genetics of *Betula*. Scand J For Res 1:421–434

Gellinek H (1997) Untersuchungen zur Holzbildungsdynamik von Birke und Kiefer an der nördlichen Waldgrenze mit Hilfe der "pinning"-Methode. Diplom Thesis, University of Hamburg

Hänninen H (1996) Effects of climate warming on northern trees: testing the frost damage hypothesis with meteorological data from provenance transfer experiments. Scand J For Res 11:17–25

Haukioja E, Koponen S (1975) Birch herbivores and herbivory at Kevo. In: Wielgolaski FE (ed) Fennoscandian tundra ecosystems, part 2. Animal and system analysis. Springer, Berlin Heidelberg New York, pp 181–188

Haukioja E, Rouhomäki K, Senn J, Suomela J, Walls M (1990) Consequences of herbivory in the mountain birch (*Betula pubescens* ssp. *tortuosa*): importance of the functional organization of the tree. Oecologia 82:238–247

Haukioja E, Ruohomaki K, Suomela J, Vuorisalo T (1991) Nutritional quality as a defence against herbivores. For Ecol Manage 39:237–245

Henriksson J, Haukioja E, Ruohomäki K (1999) Impact of leaf damage on growth of mountain birch shoots. New Phytol 142:469–474

Hoogesteger J, Karlsson PS (1992) Effects of defoliation on radial stem growth and photosynthesis in the mountain birch (*Betula pubescens* ssp. *tortuosa*). Funct Ecol 6:317–323

Junttila O, Nilsen J (1993) Growth and development of northern forest trees as affected by temperature and light. In: Alden JN, Ödum S, Mastrantonio ML et al. (eds) Forest development in cold climates. Plenum Press, New York, pp 43–57

Kallio P (1975) Kevo, Finland. In: Rosswall T, Heal OW (eds) Structure and function of tundra ecosystems. Ecol Bull 20:193–223

Kallio P, Lehtonen J (1973) Birch forest damage caused by *Oporinia autumnata* (Bkh.) in 1965–1966 in Utsjoki, N Finland. Rep Kevo Subarctic Res 10:55–69

Kallio P, Lehtonen J (1975) On the ecocatastrophe of birch forests caused by *Oporinina autumnata* (Bkh.) and the problem of reforestation. In: Wielgolaski FE (ed) Fennoscandian tundra ecosystems, part 2. Animal and system analysis, Springer, Berlin Heidelberg New York, pp 174–180

Kallio P, Mäkinen Y (1978) Vascular flora of Inari, Lapland. 4. Betulaceae. Rep Kevo Subarct Res Stat 14:38–63

Karlsson PS, Nordell O (1989) Effects of leaf duration, nutrient supply, and temperature on the seasonal pattern of growth and nitrogen uptake in tree seedlings in a subarctic environment. Can J Bot 67:211–217

Karlsson PS, Nordell O (1996) Effects of soil temperature on nitrogen economy and growth of mountain birch seedlings near its presumed low temperature distribution limit. Écoscience 3:183–189

Karlsson PS, Weih M (1996) Relationships between nitrogen economy and performance in the mountain birch (*Betula pubescens* ssp. *tortuosa*). Ecol Bull 45:71–78

Karlsson PS, Weih M (2001) Soil temperatures near the distribution limit of the mountain birch: implications for seedling nitrogen economy and survival. Arct Antarct Alpine Res 33:88–92

Karlsson PS, Weih M (2004) Patterns of recovery after insect herbivory in the mountain birch. Funct Ecol 17:841–850

Karlsson PS, Olsson L, Hellström K (1996) Trade-offs among investments in different long-shoot functions – variation among mountain birch individuals. J Ecol 84:915–921

Karlsson PS, Nordell KO, Sveinbjörnsson B (2001) Biomass and nitrogen turnover and nutrient use characteristics in subarctic mountain birch trees. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and the biosphere series, vol 27. MAB/UNSECO, Parthenon, New York, London, pp 129–143

Karlsson PS, Bylund, H, Neuvonen S, Heino S, Tjus M (2003) Climatic control of budburst in the mountain birch at two areas in northern Fennoscandia and possible responses to global change. Ecography 26:617–625

Kauppi A (1989) Sprouting in birches; a morphological and ecophysiological approach. Acta Univ Oulu Ser A Sci Rerum Naturalium 209:1–25

Kauppi A, Kiviniitty M, Ferm A (1990) Leaf morphology and photosynthetic rate in birch seedlings and stump sprouts. Can J For Res 20:952–960

Kellomäki S, Kolström M (1994) The influence of climate change on the productivity of Scots pine, Norway spruce, Pendal birch and Pubescent birch in southern and northern Finland. For Ecol Manage 65:201–217

Kira T (1975) Primary production of forests. In: Cooper JP (ed) Photosynthesis and productivity in different environments. Cambridge Univ Press, Cambridge, pp 5–40

Kjelvik S (1971) Brief report on IBP biomass studies in a mountain birch zone at Maurseth, Hardangervidda, Norway. In: Rosswall T (ed) Systems analysis in northern coniferous forests. Bull Ecol Res Com (Stockh) 14:49–53

Kjelvik S (1973) Biomass and production in a willow thicket and a sub-alpine birch forest, Hardangervidda, Norway. In: Bliss LC, Wielgolaski FE (eds) Primary production and production processes, Tundra Biome. The Tundra Biome Steering Committee, Stockholm, pp 115–122

Körner C (1989) The nutritional status of plants from high altitudes: a worldwide comparison. Oecologia 81: 379–391

Körner C (1991) Some often overlooked plant characteristics as determinants of plant growth: a reconsideration. Funct Ecol 5:162–173

Körner C (2003) Carbon limitation in trees. J Ecol 91:4–17

Kuivinen KL, Lawson MP (1982) Dendroclimatic analyses of birch in south Greenland. Arct Alpine Res 14:243–250

Kullman L (2002) Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. J Ecol 90:68–77

Lehtilä K, Tuomi J, Sulkinoja M (1994) Bud demography of the mountain birch *Betula pubescens* ssp. *tortuosa* near tree line. Ecology 75:945–955

Lehtonen J, Heikkinen RK (1995) on the recovery of mountain birch after *Epirrita* damage in Finnish Lapland, with a particular emphasis on reindeer grazing. Ecoscience 2:349–356

Lindroth RL (1996) CO_2-mediated changes in tree chemistry and tree-Lepidopteran interactions. In: Kock GW, Mooney HA (eds) Carbon dioxide and terrestrial ecosystems. Academic Press, San Diego, pp 105–120

Mikkola K (1986) Pintakasvillisuuden, puuston ja eräiden ympäristötekijöiden suhteet Luoteis-Enontekiön tunturikoivikoissa. (The relationships between vegetation, trees and some environmental factors in the mountain birch forests of north-western Enontekiö.) MSc Thesis, 120 pp, Department of Botany, University of Helsinki

Neuvonen S, Niemelä P, Virtanen T (1999) Climatic change and insect outbreaks in boreal forests: the role of winter temperatures. Ecol Bull 47:63–67

Oechel WC, Cowles S, Grulke N, Hastings SJ, Lawrence B, Prudhomme T, Reichers G, Strain B, Tissue D, Vourlitis G (1994) Transient nature of CO_2 fertilization in Arctic tundra. Nature 371:500–503

Skre O (1993) Growth of mountain birch (*Betula pubsescens* Ehrh.) in response to changing climate. In: Alden J, Mastrantonio JL, Ödum S (eds) Forest development in cold climates, Plenum Press, New York, pp 65–78

Skre O, Baxter R, Crawford MM, Callaghan TV, Fedorkov A (2001) How will the tundra-taiga interface respond to climate change? Ambio Spec Rep 12:37–46

Sonesson M, Hoogesteger J (1983) Recent tree-line dynamics (*Betula pubescens* Ehrh. ssp. *tortuosa* [Ledeb.]) in northern Sweden. Nordicana 47:47–54

Starr M, Hartman M, Kinnumem T (1998) Biomass function for mountain birch in the Vuoskojärvi integrated monitoring area. Boreal Environ Res 3:297–303

Strömgren M, Linder S (2002) Effects of nutrition and soil warming on stemwood production in a boreal Norway spruce stand. Global Change Biol 8:1195–1204

Sveinbjörnsson B (1983) Bioclimate and its effect on the carbon dioxide flux of mountain birch (*Betula pubescens* Ehrh.) at its altitudinal tree-line in the Torneträsk area, Northern Sweden. Nordicana 47:111–122

Sveinbjörnsson B (1987) Biomass proportioning as related to plant size in juvenile mountain birch near Abisko, Swedish Lapland. Rep Kevo Subarct Res Stat 20:1–8

Sveinbjörnsson B (2000) North American and European treelines: external forces and internal processes controlling position. Ambio 29:388–395

Sveinbjörnsson B, Nordell O, Kauhanen H (1992) Nutrient relations of mountain birch growth at and below the elevational tree-line in Swedish Lapland. Funct Ecol 6:213–220

Tenow O (1972) The outbreaks of *Oporinia autumnata* Bkh. and *Operophthera* spp. (Lep., Geometridae) in the Scandinavian mountain chain and northern Finland 1862–1968. Zool Bidr Uppsala Suppl 2, pp 1–107

Tenow O (1996) Hazards to a mountain birch forest – Abisko in perspective. Ecol Bull 45:104–114

Tenow O, Bylund H (2000) Recovery of a *Betula pubescens* forest in northern Sweden after severe defoliation by *Epirrita autumnata*. J Veg Sci 11:855–862

Tenow O, Nilssen AC, Holmgren B, Elverum F (1999) An insect (*Agryresthia retinella*, Lep., Yponomeutidae) outbreak in northern birch forests, released by climatic changes? J Appl Ecol 36:111–122

Tenow O, Bylund H, Karlsson PS, Hoogesteger J (2004) Rejuvenation of a mountain birch forest by an *Epirrita autumnata* (Lepidoptera: Geeometridae) outbreak. Acta Oecologica 25:43–52

Thórsson AT, Salmela E, Anamthawat-Jónsson K (2001) Morphological, cytogenetic, and molecular evidence for introgressive hybridization in birch. J Hered 92:404–408

Verwijst T (1988) Environmental correlates of multiple-stem formation in *Betula pubescens* ssp. *tortuosa*. Vegetatio 76:29–36

Warren WG (1980) On removing the growth trend from dendrochronological data. Tree Ring Bull 40:35–44

Weih M (1998a) The nitrogen economy of mountain birch as related to environmental conditions and genotype. PhD Thesis, University of Uppsala, Sweden. Comprehensive summaries Uppsala Diss, Faculty of Science and Technology 351

Weih M (1998b) Seasonality of nutrient availability in soils of subarctic mountain birch woodlands, Swedish Lapland. Arct Alp Res 30:19–25

Weih M (2000a) Delayed growth response of mountain birch seedlings to a decrease in fertilisation and temperature. Funct Ecol 14:566–572

Weih M (2000b) Growth of mountain birch seedlings in early-successional patches: A year-round perspective. Plant Biol 2:428–436

Weih M, Karlsson PS (1997) Growth and nitrogen utilization in seedlings of mountain birch (*Betula pubescens* ssp. *tortuosa*) as related to plant nitrogen status and temperature: a two-year study. Écoscience 4:365–373

Weih M, Karlsson PS (1999a) The nitrogen economy of mountain birch seedlings: implications for winter survival. J Ecol 87:211–219

Weih M, Karlsson PS (1999b): Growth response of altitudinal ecotypes of mountain birch to temperature and fertilisation. Oecologia 119:16–23

Weih M, Karlsson PS (2001a) Growth response of mountain birch to air and soil temperature: is increasing leaf-nitrogen content an acclimation to lower air temperature? New Phytol 150:147–155

Weih M, Karlsson PS (2001b) Variation in growth patterns among provenances, ecotypes and individuals of mountain birch. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man Biosphere Ser 27:143–154

Weih M, Karlsson PS (2002) Low winter soil temperature affects summertime nutrient uptake capacity and growth rate of mountain birch seedlings in the subarctic, Swedish Lapland. Arct Antarct Alpine Res 34:434–439

Weih M, Karlsson PS, Skre, O (1998a) Intra-specific variation in nitrogen economy among three mountain birch provenances. Ecoscience 5:108–116

Weih M, Johanson U, Jones DG (1998b) Growth and nitrogen utilization in seedlings of mountain birch (*Betula pubescens* ssp. *tortuosa*) as affected by ultraviolet radiation (UV-A and UV-B) under laboratory and natural conditions. Trees 12:201–207 and 12:452 [Erratum]

6 Effects of Temperature Changes on Survival and Growth in Mountain Birch Populations

O. Skre, J. Nilsen, M. Naess, B. Igeland, K. Taulavuori,
E. Taulavuori and K. Laine

6.1 Introduction

Over the last 100 years, mean annual temperatures in the northern hemisphere have increased by about 1.5 °C, with a temporary warm period in the 1930s followed by a colder period in the years 1965–1980 (see Chap. 1). In the last 20 years, there has been a strong increase of about 1.0 °C in global temperatures. The temperature has shown cyclic variations due to the activity of the North Atlantic Oscillation (NOA), and expressed by annual mean temperatures or annual temperature range (Crawford et al. 2002). Over the last 50 years a steady increase in the CO_2 concentrations in the atmosphere from 315 to 360 ppm has been recorded (Callaghan 1993). The recent increase in global CO_2 is mainly due to increased output of fossil fuel. Increased CO_2 is in turn expected to lead to higher absorption rates of long-wave radiation in the atmosphere (the greenhouse effect), thereby increasing temperatures. According to predictions, a future doubling of the CO_2 concentrations from 360 to 720 ppm would result in a 3–4 °C increase in mean winter temperatures and 1–2 °C increase in summer temperatures in the northern hemisphere (Callaghan 1993).

The impact of raised temperature on sensitive stages like seed reproduction, winter dormancy, migration rates and soil conditions (Callaghan 1993; Heide 1993; Huntley 1997) is expected to affect subarctic plant species. Higher CO_2 levels will normally cause increased growth rates due to a combination of greater photosynthetic rates and water use efficiency (Hall et al. 1993). In most deciduous trees, e.g. birch, shoot growth will take place over the whole season ('free growth') and there will be no sink limitation on photosynthesis.

Thornley (1972) developed a model for balanced shoot/root growth at varying temperatures by regulating the C/N ratio. The expected CO_2 increase would lead to a higher C/N ratio that would have to be balanced by increased root growth. The most pronounced effect of increased CO_2 is therefore an

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

increase in root biomass (Mousseau 1993). In birch, these compensation mechanisms have also been found. Most of these experiments have been carried out at considerably higher temperatures (15–30 °C) and lower photosynthetic active radiation than under ambient field conditions at higher latitudes (cf. Mortensen 1998). Higher summer temperatures would also lead to temperature acclimation, i.e. the temperature responses of the Rubisco enzyme will be changed, leading to a higher temperature optimum for photosynthesis (Skre 1993a). In the long term, it would lead to genetic adaptation of plant species and ecotypes. Higher soil temperatures would cause more rapid decomposition and uptake rates of nitrogen in soil (see Chap. 5), and increased summer temperatures would also lead to better seed quality, and thereby to improved seed reproduction in forest tree species (e.g. Mork 1957).

Genetic ecotypes have also developed in response to day length and temperature regarding dormancy induction and to temperature regarding dormancy breaking (chilling requirements). The chilling requirements increase with decreasing latitude due to a longer growing season (Myking and Heide 1995). When plants come out of dormancy, higher temperatures would lead to earlier dehardening, which may lead to a higher frequency of spring frost damage (Hänninen 1996), particularly in ecotypes from northern and inland areas (Larsen 1976). This damage may lead to reduced growth the following season.

In the present review, the effects of raised winter temperatures due to increased CO_2 levels on growth and carbon balance in some birch provenances have been studied. Mountain birch (*Betula pubescens* ssp. *czerepanovii*) is a major constituent of northern forests in northern Europe (see Chap. 1), and because it is an old inhabitant of Scandinavia, climatically adapted ecotypes have also evolved.

In order to elucidate the mountain birch responses to the expected changes in winter temperature levels, three different aspects of the climate × birch relationships will be discussed in more detail, i.e.

- to see how birch growth and carbon balance are influenced by summer and winter temperatures in field (and greenhouse) experiments.
- to compare the responses of mountain birch seedlings from different origins to different temperatures and CO_2 levels in order to investigate possible adaptation mechanisms, and to see how the winter temperature responses are modified by different CO_2 levels.
- to see how different winter temperature levels may influence dormancy, frost hardiness and growth in birch seedlings the following season.

6.2 Results and Discussion

6.2.1 Field and Greenhouse Experiments at Different Temperatures

To investigate the influence of the expected climate change on tree growth and carbon balance, Skre (1993b) transplanted birch seedlings of different origins (Table 6.1) grown in fertilized peat (see Skre 1991 for composition) to two oceanic sites in southwestern Norway (60°N), one lowland site (50 m) and another upland site near the tree line at 450-m altitude. Growth rates as measured by biomass values were four times higher at the lowland site than at the high altitude site by the end of the 2-year period (Table 6.2). At the lowland site the highest growth rates were found in seedlings from the southern lowland mountain birch (BAM) and silver birch (*Betula pendula*) provenances

Table 6.1. Localities and altitudes of birch seed populations

	Locality			Altitude (m)
BAL[a]	Løten, SE Norway	60°51′N	11°20′E	200
BAM	Løten, SE Norway	60°51′N	11°20′E	200
BS	Fana, SW Norway	60°16′N	5°22′E	50
BH	Blefjell, SE Norway	59°45′N	9°28′E	750
IH	Hafnaskogur, Iceland	64°23′N	21°40′W	50
NMe	Melbu, N Norway	68°37′N	14°27′E	20
BJ	Kevo, N Finland	69°44′N	27°00′E	200
NHa	Hammerfest, N Norway	70°40′N	23°41′E	50

[a] Silver birch (*Betula pendula*)

Table 6.2. Total biomass (g/plant) at peak season in 2-year-old seedlings of mountain birch (*Betula pubescens*) and silver birch (*B. pendula*) grown in fertilized peat at two different altitudes, i.e. Fana (50 m) and Kvamskogen (450 m) in western Norway (60°N). Means ±2 SE. See Table 6.1 for origin of seed populations

Origin	Kvamskogen	Fana
BJ	1.6±0.2	1.9±0.4
BH	3.0±0.4	7.9±1.4
BS	6.8±0.7	17.5±2.7
BAM	4.6±0.6	25.2±4.0
BAL	3.2±0.6	26.1±3.8

(BAL), while at the tree-line site the seedlings originating from the southern alpine provenance (BH) and the local provenance from western Norway (BS) were most successful. At the tree-line site, the southern lowland provenances were found to suffer frost damage (Skre 1993b) due to retarded growth cessation in fall.

In accordance with Mäenpää et al. (2001), there was a sharp drop in total carbohydrates in the stem and root tissue after bud break, as related to shoot growth, and the strongest carbohydrate depletion was found at the low-level Fana site (see Fig. 6.1) where growth rates were highest. The nitrogen con-

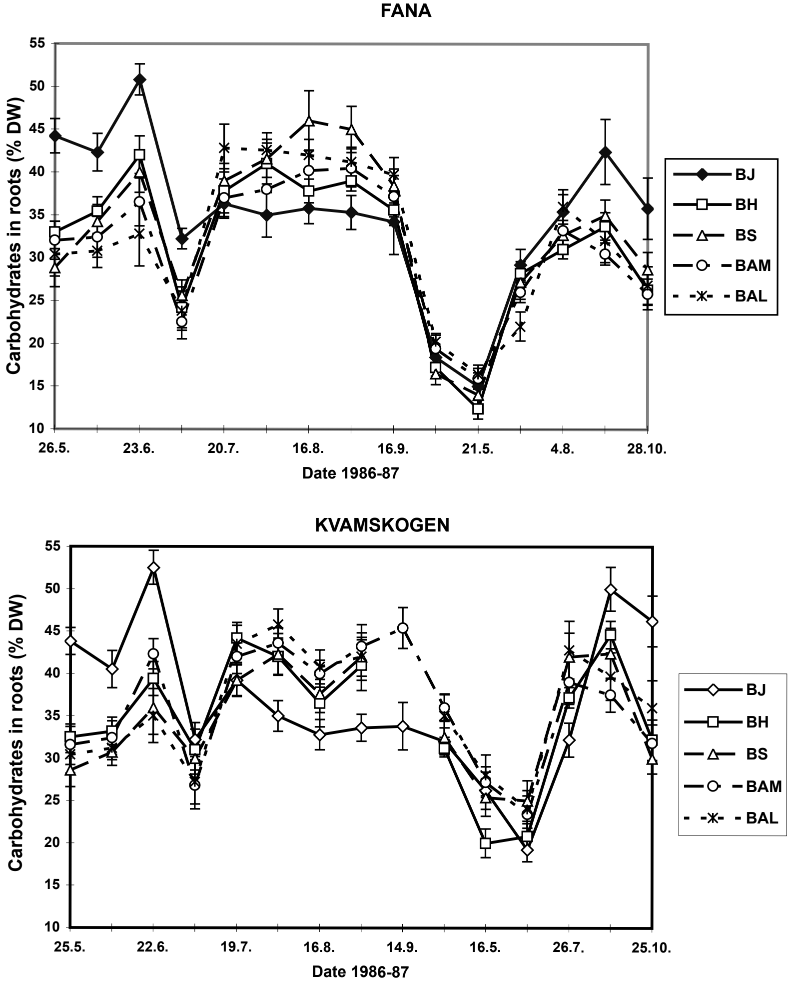


Fig. 6.1. Total non-structural carbohydrate content as percentage dry weight in roots of birch seedlings over two seasons (1986–1987) at two different altitudes, i.e. Fana (50 m) and Kvamskogen (450 m) in western Norway (59°N). Means ±2 SE. See Table 6.1 for locations of seed populations. (cf. Skre 1993b)

tent in roots showed an almost inverse relationship to the carbohydrate content, i.e. when root nitrogen content is high, indicating root growth, the carbohydrates tend to be incorporated into structural tissue and used for growth.

Experiments in a controlled environment (Skre 1993a) showed that the carbohydrate content in root tissue of arctic as well as the southern alpine ecotypes was higher than in southern lowland ecotypes. This agrees well with earlier findings on alpine plants in, e.g. Alaska, because in a nutrient-poor environment with low competition, plants tend to avoid growth rather than produce nutrient-deficient tissue (Chapin 1979). The seedlings from the northern population (BJ) also had slightly higher photosynthesis rates than the southern populations at 21 °C (Fig. 6.2). This is called metabolic compensation (Mooney and Billings 1961; Crawford 1989) and is regarded as a compensation for a relatively shorter growing season in northern areas. Strong acclimation effects due to rapid changes in temperature were also found (cf. Billings et al. 1971). At medium temperatures (10–15 °C), when photosynthesis rates were high, the shoot/root ratios as well as the specific leaf areas and leaf area ratios were low, indicating a higher proportion of structural tissue than when temperatures were higher and less favourable for photosynthesis (see Fig. 6.3). By increasing root growth at high temperatures, plants may be able to absorb more nitrogen from the soil and compensate for the high temperatures by increasing their photosynthetic capacity (cf. Thornley 1972). In

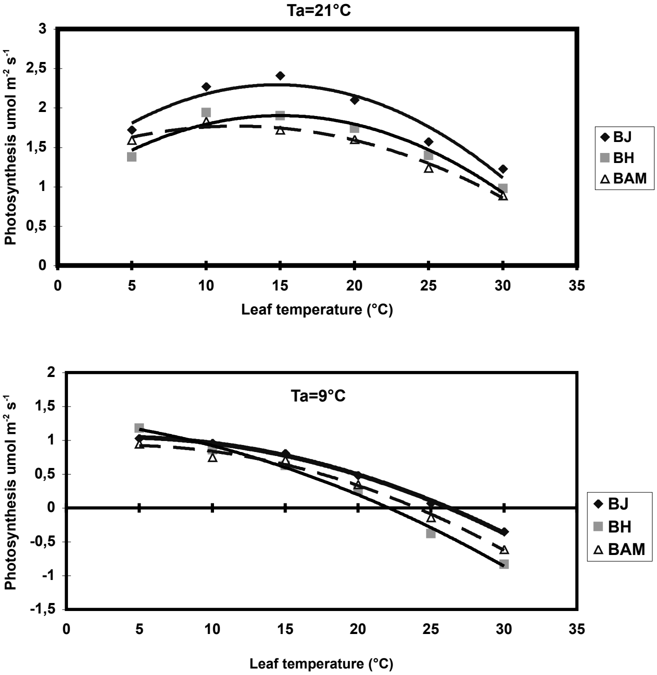
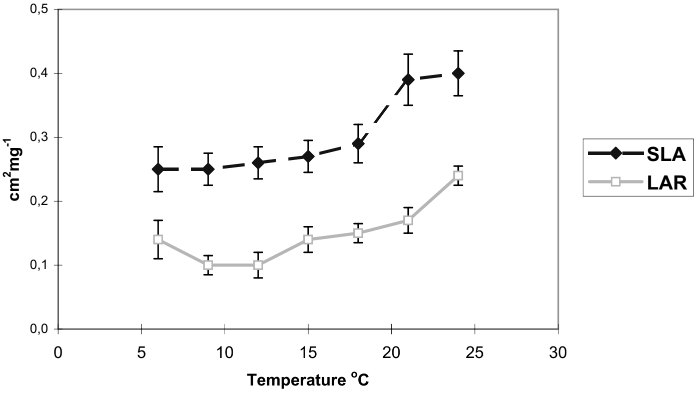


Fig. 6.2. Photosynthesis rates (μM CO_2 m^{-2} s^{-1}) as a function of temperature in discs of mature leaves from three mountain birch populations (see Table 6.1). Leaves were kept for 3 weeks at an 18-h photoperiod and at 21 and 9 °C, respectively. Irradiance was 100 μM m^{-2} s^{-1}. (See Skre 1993a for details)



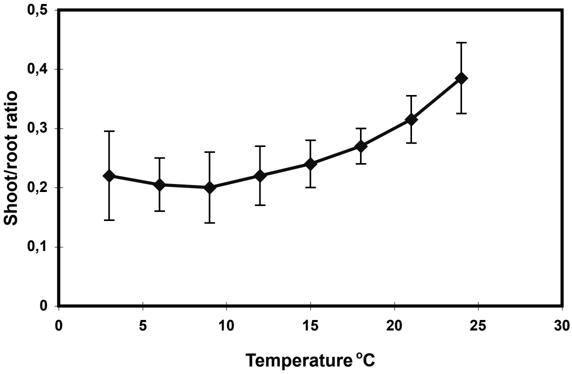


Fig. 6.3. Leaf area ratios (*LAR*) and specific leaf area (*SLA*) in $cm^2\ mg^{-1}$ (*above*) and shoot/root ratios (*below*) with ±2 SE. in 6-week-old mountain birch seedlings from a subalpine area in southern Norway (BH). (See Skre 1993a for details)

field experiments with birch seedlings, the nitrogen uptake rates in roots have been found to be strongly affected by soil temperatures, leading to increased leaf productivity and increased growth rates (see Chap. 5).

Respiration rates increased in leaf and stem tissue when birch seedlings were grown for 6 weeks at low temperatures, and decreased in roots, compared to plants grown at high temperatures (Skre 2001). Most of this low temperature-induced increase has been shown to be cyanide-resistant, i.e. not related to growth, particularly at low nutrient levels. The high temperature-induced respiration increase in roots, however, is mostly growth-related. The ecological significance is that a respiration-induced increase in root growth may increase nitrogen absorption rates and lead to increased photosynthetic capacity at high temperatures, while at low temperatures and nutrient levels increased cyanide-resistant respiration rates in shoot and leaf tissue would prevent growth under unfavourable conditions (see Skre 2001). Chemical analysis of birch tissue confirmed the results from the growth measurements. Mountain birch seedlings increased their nitrogen and chlorophyll concentration in leaves in response to elevated temperatures, at the same time, there was a strong decrease in the total nitrogen and carbohydrate concentration in stem and root tissue (Skre 1993a).

6.2.2 Winter Temperature and CO_2 Experiments

Seedlings of mountain birch (*Betula pubescens*) from one of the same populations (BH) as in the former experiment and two other populations, one (NH) northern and one (IH) from Iceland (see Table 6.1), were given two different levels of nutrients and kept during the winter at ambient and +4 °C above normal winter temperatures. The following spring the plants were moved into open top chambers at 350 and 650 ppm CO_2 and the shoot elongation was followed during the season, all plants having approximately the same light, temperature and photoperiod conditions (see Skre and Naess 1999).

One important result from the experiment in the open top chambers was that plants from the southern alpine population increased their growth during the following season after treatment in elevated winter temperatures, while plants from the two more northern birch populations (IH and NH) showed negative responses (Fig. 6.4). The southern alpine plants also showed a slight positive response in shoot elongation rates when grown at elevated CO_2 levels, while there were no significant responses in the Icelandic population (IH). All three populations showed a positive response to added nutrients, and in the southern birch population there was also a strong increase in

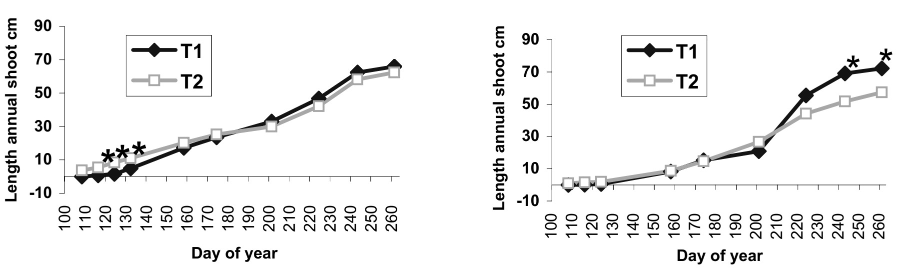


Fig. 6.4. Shoot elongation (mean length, longest shoot L_{max} in cm) during the 1994 season in two investigated populations. *Left* Blefjell, SE Norway, *right* Hafnaskogur, Iceland. Significant differences are shown by *asterisks* where *$p<0.05$ (after Skre and Naess 1999). Fertilized plants grown at ambient CO_2 levels and at two different winter temperatures, *T1* ambient and *T2* ambient +4 °C

CO_2 responses after nutrient addition; this response was weaker in the two northern populations. As a consequence, increased winter temperatures may extend the growth season (cf. Myking and Heide 1995), particularly in southern ecotypes, leading to increased growth. The results agree well with previous studies (e.g. Skre 1993a; Murray et al. 1994), indicating that ecotypes and species that are competitive and adapted to a high-growth strategy may take advantage of the expected climate change, because they would tend to put more of their carbon and nutrients into new growth, while the northern populations tend to use their resources for storage and defence against climatic and herbivore stress, which seem to be more important selective factors in northern areas than competition (Chapin 1980; Ågren 1985; see also Figs. 6.1–6.3 and Chap. 5). As for the Icelandic population, a certain inbreeding with the slow-growing *Betula nana* is also possible (Elkington 1968; Anamthawat-Jonsson and Tomasson 1990), probably as a result of selective sheep grazing (Blöndal 1993, see also Chap. 1).

6.2.3 Dormancy and Frost Hardiness in Mountain Birch Provenances as Influenced by Winter Temperatures

The winter dormancy in forest tree species (e.g. Håbjørg 1972; Skre 1988) is induced mainly by short days, and is only slightly influenced by temperature. As soon as the low temperature requirements for dormancy breaking have been fulfilled, however, high temperatures would promote bud break and metabolic activity in buds (Ritchie 1982; Heide 1993). Earlier bud break may in turn make trees more susceptible to spring frost damage (e.g. Hänninen 1996), but the dehardening process is often slower and only partly dependent on dormancy breaking (Skre 1988). In some species, higher winter temperatures may lead to delayed bud break because they need more time to have their low temperature requirements fulfilled (Murray et al. 1994). In birch, however, the chilling requirements have been shown to be relatively low, and the overall effect of the expected increased winter temperatures is earlier dormancy breaking and a longer growth period (Myking and Heide 1995). On the other hand, very few investigations have been carried out to see how the dehardening process in birch might be influenced by the expected increase in winter temperatures, i.e.

1. to investigate the winter dormancy and spring frost resistance in birch provenances as influenced by winter temperatures,
2. to see how these changes in winter dormancy and spring frost resistance may influence growth during the following season.

Seedlings of different mountain birch populations (the last five in Table 6.1) were raised in a greenhouse at 69°40′N (Nilsen, unpubl.) before hardening and dormancy induction, and transferred to temperature-controlled greenhouses (at 60°24′N) with ambient and +4 °C higher temperatures, respectively. The stems were subjected to controlled freeze–thaw cycles prior to a frost hardiness test based on electrolyte leakage (Taulavuori et al. 2001). The time to bud break and the growth after bud break were recorded by destructive and non-destructive methods.

The LT50, i.e. the temperature at 50 % lethality of tissue, showed that the southern alpine population (BH) was generally slightly less hardy than the northern populations (BJ and NH). In all these plants high winter temperature treatment seemed to have had a strong negative effect on frost hardiness. In the Icelandic population (IH), however, the high temperature-treated plants stayed hardy during most of the winter, until March (Taulavuori et al. 2004). In accordance with the frost hardiness data, the northernmost high temperature-treated plants came out of dormancy much earlier than those from Iceland. The bud break in all populations seemed to occur earlier in plants treated with elevated winter temperatures than in plants grown at ambient temperatures. Biomass of stem and leaf tissue in the two northernmost populations was significantly lower after growing the plants at elevated winter temperatures than after ambient winter temperature treatment at 60°24′N (Skre, unpubl.). The total biomass as well as the total acumulated shoot lengths, however, were significantly higher after elevated winter temperature treatment in the southern populations than in the two northern populations (Skre, unpubl.), while the Iceland (IH) population was indifferent. These results are in accordance with Skre and Naess (1999). Corresponding plants grown at ambient winter temperatures at 69°40′N (Igeland, unpubl.) kept their hardiness much longer than plants overwintering at 60°24′N, probably as a result of 3–4 °C lower temperatures, and even in mid-April the LT50 was below −25 °C.

The observations on date of bud break were partly in agreement with the dehardening conditions, i.e. the most hardy populations and treatments were also those with the latest bud break. The plants retained the winter buds for a long time after they had lost their frost hardiness. In plants treated at low (ambient) temperatures, the time of bud break corresponded to the time when they lost their hardiness. In earlier studies on, e.g. Douglas fir, the needles stayed in a hardened condition for a long time after they came out of dormancy (Ritchie 1982). The present study indicates that southern subalpine boreal trees may in the future lose their hardiness before they come out of dormancy, which is expected to leave cambial tissue and needles less protected against spring frost damage. Comparisons with ambient temperatures at the origin of the seed populations (Taulavuori et al. 2004) indicate that northern lowland and coastal populations (NMe and NH) also may become more exposed to spring frost damage in the future, while the extreme oceanic Iceland population (IH) as well as the extreme continental Kevo population (BJ) appear more protected, having adapted a high spring frost tolerance (IH) or by large differences between ambient winter temperatures and the critical temperatures (LT50) for spring frost damage (BJ). In comparison, Larsen

(1976) found that coastal provenances of Douglas fir (*Pseudotsuga menziesii*) from British Columbia were more resistant to spring frost than inland provenances from the Rocky Mountains. He explained this as an adaptation to a long spring season with varying temperatures, in contrast to the inland Douglas populations.

6.3 Conclusions

Generally, in northern areas where competition from other plants is low and climate and herbivore stress are high, it is more important for plants to invest carbon and nutrients into storage and defence substances than into new growth. The present case studies seem to support these conclusions, and also agrees with earlier studies on mountain birch by, e.g. Körner (1989), Mäenpää et al. (2001) and Partanen et al. (2001). The summer temperature strongly affects growth and carbon balance during the season in birch seedlings according to temperature and day length conditions at their habitat, but the plants are to a certain degree able to compensate for these changes in order to maintain balanced shoot and root growth and reallocate nutrients and carbon to actively growing sites. Shoot and biomass growth is limited by soil temperature and its effect on nitrogen and phosphorus uptake rates. Increased winter temperatures seem to promote growth in fast-growing southern ecotypes and reduce shoot and biomass growth in continental ecotypes, partly by exposing plants more frequently to spring frost damage. CO_2 and nutrient levels may to a certain extent modify the temperature responses, and the responses to CO_2 and nutrients are found to be strongest in southern fast-growing populations. Extreme oceanic and continental ecotypes seem to be more protected from such damage than intermediate mountain birch populations.

References

Ågren GI (1985) Limits to plant production. J Theor Biol 113:89–92

Anamthawat-Jonsson K, Tomasson T (1990) Cytogenetics of hybrid introgression in Icelandic birch. Hereditas 11:65–70

Billings WD, Godfrey PJ, Chabot BF, Bourque DF (1971) Metabolic acclimation to temperature in arctic and alpine ecotypes of *Oxyria digyna*. Bull Ecol Soc Am 49:68–69

Blöndal S (1993) Socoieconomic importance of forests in Iceland. In: Alden J, Mastrantonio JL, Ødum S (eds) Forest development in cold climates. Plenum Press, New York, pp 1–14

Callaghan TV (1993) Biospheric feedback mechanisms to a changing climate in the North. In: Holten JI, Oechel WC (eds) Impacts of climatic change on natural ecosystems with emphasis on boreal and arctic/alpine areas. NINA/DN, Trondheim, Norway, pp 9–11

Chapin FS III (1979) Nutrient uptake and utilization by tundra plants. In: Underwood LS, Tieszen LL, Callahan AB, Folk GE (eds) Comparative mechanisms of cold adaptation. Academic Press, New York, pp 215–234

Chapin FS III (1980) The mineral nutrition of wild plants. Annu Rev Ecol Syst 11:238–260

Crawford RMM (1989) Studies in plant survival. Studies in ecology, vol 11. Blackwell, Oxford, 296 pp

Crawford RMM, Jeffree CE, Rees WG (2002) Paludification and forest retreat in northern oceanic environments. Ann Bot 90:1–14

Elkington TT (1968) Introgressive hybridization between *Betula nana* L. and *B. pubescens* Ehrh. in northwest Iceland. New Phytol 67:44–63

Håbjørg A (1972) Effects of photoperiod and temperature on growth and development of three latitudinal and three altitudinal populations of *Betula pubescens*. Ehrh. Meld Nor LandbrHøgsk 51(2):1–27

Hänninen H (1996) Effects of climatic warming on northern trees: testing the frost damage hypothesis with meteorological data from provenance transfer experiments. Scand J For Res 11:17–25

Hall DO, Scurlock JMO, Bolhar-Nordenkampf HR, Leegood RC, Long SP (1993) Photosynthesis and production in a changing environment. Chapman and Hall, London, 464 pp

Heide OM (1993) Daylength and thermal time responses of budburst during dormancy release in some northern deciduous trees. Physiol Plant 88:531–540

Huntley B (1997) The responses of vegetation to past and future climate changes. In: Oechel WC, Callaghan TV, Gilmanov TI, Holten JI, Maxwell B, Molau U, Sveinbjörnsson B (eds) Global change and arctic terrestrial ecosystems. Ecological studies 124. Springer, Berlin Heidelberg New York, pp 290–311

Körner C (1989) The nutritional status of plants from high altitudes. A worldwide comparison. Oecologia 81:379–391

Larsen JB (1976) Untersuchungen über die Frostempfindlichkeit von Douglasienherkünften und über den Einfluss der Nährstoffversorgung auf die Frostresistenz der Douglasie. Forst Holz Wirtsch 31(15):299–302

Mäenpää E, Skre O, Malila E, Partanen R, Wielgolaski FE, Laine K (2001) Carbon economy in birch-dominated ecosystem species in northern Fennoscandia. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. MAB series, vol 27. UNESCO, Paris and Parthenon, New York, pp 93–114

Misund S, Nilsen J, Junttila O (2001) Studies of apical growth cessation in dwarf birch (*Betula nana* L.) from Spitzbergen and northern Norway. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. MAB series, vol 27. Parthenon, New York, pp 195–206

Mooney HA, Billings WD (1961) The annual carbohydrate cycle of alpine plants as related to growth. Am J Bot 47:594–598

Mork E (1957) Om frøkvalitet og frøproduksjon hos furu i Hirkjølen (in Norwegian). Meddr Norske SkogforsVes 15:349–379

Mortensen LM (1998) Effects of elevated CO_2 concentration on growth of *Betula pubescens* Ehrh. in different climatic conditions. Scand J For Res 13:197–203

Mousseau M (1993) Effects of elevated CO_2 on growth, photosynthesis and respiration of sweet chestnut (*Castanea sativa* Mill.). In: Rozema J, Lambers H, van der Geijn SC, Cambridge ML (eds) CO_2 and biosphere. Kluwer, Dordrecht, pp 413–420

Murray MB, Smith RI, Leith ID, Fowler D, Lee HSJ, Friend AD, Jarvis PG (1994) Effects of elevated CO_2, nutrition and climatic warm wind on bud phenology in Sitka spruce

(*Picea sitchensis*) and their impact on the risk of frost damage. Tree Physiol 14:691–706

Myking T, Heide OM (1995) Dormancy release and chilling requirements of buds of latitudinal ecotypes of *Betula pendula* and *B. pubescens*. Tree Physiol 15:697–704

Partanen R, Wielgolaski FE, Malila E, Mäenpää E, Laine K (2001). Inorganic nutrient content in plant species of a mountain birch dominated ecosystem in northern Fennoscandia. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. MAB Series, vol 27. UNESCO, Paris and Parthenon, New York, pp 155–172

Ritchie GA (1982) Carbohydrate reserves and root growth potential in Douglas-fir seedlings before and after cold storage. Can J For Res 12(4):905–912

Skre O (1988) Frost resistance in forest trees – a literature survey. Medd Nor Inst Skogforsk 40(9):1–35

Skre O (1991) Growth experiments with seedlings of mountain birch (*Betula pubescens* Ehrh.) and lowland birch (*Betula pendula* Roth.) grown at varying temperature, light and daylength. Medd Nor Inst Skogforsk 44(6):1–41

Skre O (1993a) Growth of mountain birch (*Betula pubescens* Ehrh.) in response to changing temperature. In: Alden J, Mastrantonio JL, Ødum S (eds) Forest development in cold climates. Plenum Press, New York, pp 65–78

Skre O (1993b) Effects of altitude on growth in ecotypes of mountain birch (*Betula pubescens* Ehrh.) and lowland birch (*Betula pendula* Roth.) seedlings. Medd Nor Inst Skogforsk 45(11):1–30

Skre O (2001) Temperature adaptations in growth and carbon balance in relation to nutrient level in seedlings of *Betula pubescens* from different populations in Scandinavia. Iceland For Assoc Skogræktarritid 2001(1):156–162

Skre O, Naess M (1999) CO_2 and winter temperature effects on white birch. Chemosphere Global Change Science 1:469–483

Taulavuori K, Taulavuori E, Niinimaa A, Laine K (2001) Acceleration of frost hardening in *Vaccinium vitis-idaea* (L.) by nitrogen fertilization. Oecologia 127:321–323

Taulavuori K, Taulavuori E, Skre O, Nilsen J, Igeland B, Laine KM (2004) Dehardening of mountain birch (*Betula pubescens* ssp. *czerepanovii*) ecotypes at elevated winter temperatures. New Phytol 162:427–436

Thornley JHM (1972) A balanced quantitative model for root:shoot ratios in vegetative plants. Ann Bot 36:431–444

7 Phenology and Performance of Mountain Birch Provenances in Transplant Gardens: Latitudinal, Altitudinal and Oceanity–Continentality Gradients

J.A. Ovaska, J. Nilsen, F.E. Wielgolaski, H. Kauhanen, R. Partanen,
S. Neuvonen, L. Kapari, O. Skre and K. Laine

7.1 Introduction

Phenology is the study of timing of annually recurring events in plants, especially in relation to year-to-year variation in environmental factors. In forestry, it has been known for many years that transplantation of coniferous tree provenances between southern and northern latitudes has a considerable impact on both phenology and productivity of the trees (Hagem 1931; Kalela 1938; Heikinheimo 1949; Magnesen 1992; Beuker 1994). It has, for instance, been observed that bud break and flowering occur earliest in trees of the northernmost origin when grown under uniform conditions in a transplant garden (Reader 1982; Beuker 1994). They also end growth earliest in autumn (Morgenstern 1996). Generally, the photoperiod has been found to be the dominant factor in determining the cessation of growth in northern plants (Partanen and Beuker 1999). The long-continuing growth of southern provenances planted further north has often caused a weak hardening of the shoots by the end of the summer, which has resulted in frost damage during winter and spring.

Transplantation experiments are often used in determining the degree of ecotypic differentiation among different provenances of a tree species. In a transplantation experiment, seedlings or micropropagated saplings of different provenances are transferred to given environmental conditions and their responses are then determined. When the provenances are grown under uniform conditions for comparative ecophysiological research, all the observed phenotypic differences among the provenances are due to differences in their genotypes – provided that the transplants of different provenances have been treated in the same way before and during transplantation. These different responses may be used to estimate the degree of ecotypic differentiation within a tree species. On the other hand, when the same provenance or geno-

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

type is grown in varying habitats and its response to different environmental conditions then determined, a knowledge of phenotypic plasticity of a provenance or genotype is obtained.

In the present study, populations of *Betula pubescens*, and mainly of mountain birch (ssp. *czerepanovii*) of southern and northern, as well as of oceanic and more continental origin and from various elevations, were transferred to different transplant gardens north of the Arctic Circle. These transplant gardens are situated in an oceanity–continentality gradient and at different altitudes in northwestern Fennoscandia and northeastern Finland (Fig. 7.1). Different provenances were grown in the transplant gardens for 10 years or more. The aim of the present study is to determine the differences in survival and in the phenological and growth responses among different birch provenances under varying environmental conditions and compare the results with earlier findings.

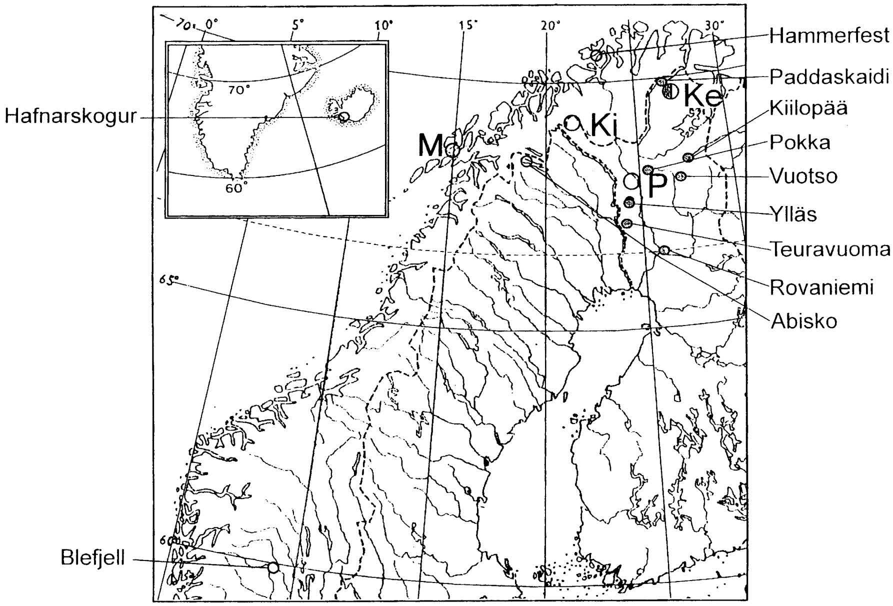


Fig. 7.1. Map showing the location of five transplant gardens and the origin of seedling progenies (provenances) used in the study. Transplantation sites are marked with *large dots*, *M* Melbu (10 m a.s.l., in coastal area), *Ki* Kilpisjärvi (510 m a.s.l., just below altitudinal tree line), *P* Pallasjärvi (320 m a.s.l., far below altitudinal forest line) and *Ke* Kevo (low-elevation garden: 100 m a.s.l., at river valley; high-elevation garden: 280 m a.s.l., at forest line). *Open dots* Provenances grown in Melbu, Kilpisjärvi and Pallasjärvi gardens, *filled dots* provenances grown in Kevo gardens, *half-filled dots* the provenance is grown both in the three former and two latter gardens

7.2 Material and Methods

Results from five transplant gardens (Fig. 7.1) are reviewed in the present study and compared with the results of older studies. Only the high-elevation garden near the Kevo Subarctic Reasearch Station is characterized by relatively nutrient-rich soil. More details of the sites are given in the enclosed CD.

The age of the birches used in the study varied among the transplant gardens. In the Kevo gardens, the seeds were germinated in 1974 and the saplings were planted in 1977, while the material for the Melbu, Kilpisjärvi and Pallasjärvi gardens (Fig. 7.1) was germinated in 1991 and planted in 1992. The mother trees for the Kevo gardens came from different latitudes and altitudes in northern Finland, and the plants in the other transplant gardens originated from southern and northern Norway, northern Sweden and Finland, and from Iceland (see Fig. 7.1; more details in the enclosed CD).

Differences among the provenances at the five transplant gardens were recorded for plant survival, time of leafing (bud burst), foliage senescence (autumnal coloration) and leaf fall. Total height and diameter measurements of the study trees are measured annually, but only data for certain years are given here. More detailed growth measurements will be presented elsewhere (see also, e.g., Chap. 4 and the enclosed CD for more details).

7.3 Results and Discussion

7.3.1 Transplantation Stress and Seedling Survival

When considering the phenological and growth responses of different provenances to the prevailing environmental conditions after transplantation, we often find features typical of each provenance. These characteristics are usually signs of ecotypic differentiation to the original habitat of a provenance and are thus the result of genotypic adaptation. However, a given provenance may be exposed to heavy environmental stress after transplantation due to, e.g. a remote latitudinal distance, an altitudinal difference or a great oceanity–continentality change between its original habitat and the transplantation site. Hence, it is sometimes difficult to distinguish whether the phenological and growth responses of transplants are genotypic adaptations characteristic of a plant in its original habitat or whether they are just phenotypic adjustments in response to transplantation procedure. On the other hand, however, if there are clear differences in seedling survival among the provenances it may be concluded that some provenances are suffering more from transplantation than others. Long-distance latitudinal transfer has been observed to have a negative impact on many tree species (e.g.

Carter 1996) and the same is obvious also in birch (Eriksson and Jonsson 1986).

In terms of the survival of seedlings grown in the Melbu, Kilpisjärvi and Pallasjärvi transplantation sites (see Fig. 7.1), it was clear that the seedlings of the southernmost provenance (Blefjell) suffered most from the transplantation to northern areas (Fig. 7.2). Moreover, the other relatively southern provenance (Hafnarskogur) had a very low survival rate in the Kilpisjärvi site, while it survived well in the more oceanic Melbu site at approximately the same latitudinal location. The birches from southern Greenland (Narssarssuaq) at first (1994) showed relatively good survival in Melbu, but in 2002 they had the lowest survival value. The oceanic Melbu provenance had a high mortality in the Kilpisjärvi site, however, it survived in the more continental site in Pallasjärvi. Survival in both the most oceanic Melbu and most continental Pallasjärvi sites was approximately equally good. The reduced survival of all provenances in Kilpisjärvi was most probably caused by a combination of severe high-altitude conditions and damage by herbivores (willow grouse and hare in winter, *Epirrita* larvae in summer; Rauni Partanen, pers. observ.). With regard to the Kevo gardens, the southernmost provenance (Rovaniemi) had clearly visible injuries (frost or drought damage), which were especially common in the patches of a very dry and sandy soil in the lower garden. This suggests that, in addition to the stress caused by a long-distance transfer of a provenance from its original habitat, edaphic factors in a new environment may play an important role in the susceptibility of a given provenance to damage after transplantation.

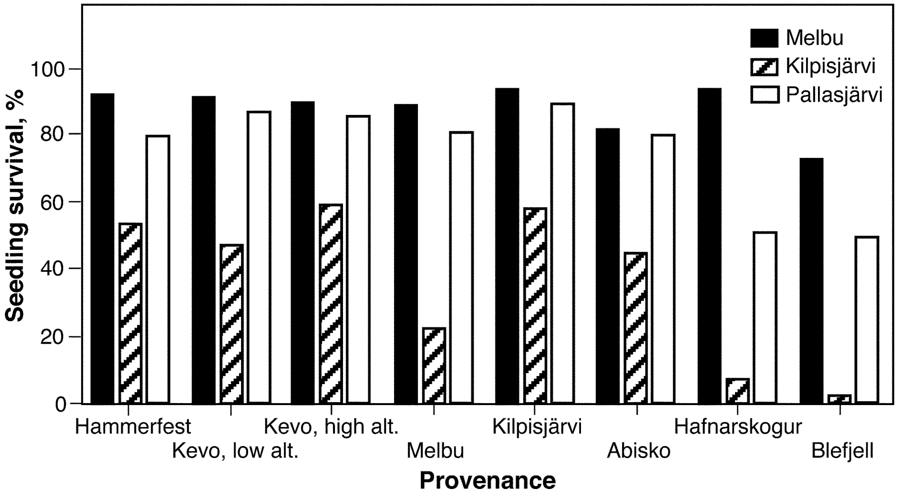


Fig. 7.2. Seedling survival 2 years after planting for different provenances in Melbu, Kilpisjärvi and Pallasjärvi transplantation sites. Note that the low survival in Kilpisjärvi was partly caused by damage from herbivores

7.3.2 Spring Phenology (Bud Burst)

According to e.g. Myking and Heide (1995) and Myking (1997, 1999), when *B. pubescens* ecotypes were growing under uniform environmental conditions, southern, coastal and high-altitude ecotypes had later bud burst than northern, inland and low-altitude ones. This means that the thermal sum requirement for bud burst is higher in the former than in the latter. With regard to the Melbu, Kilpisjärvi and Pallasjärvi transplantation sites, the mean date for bud burst was, indeed, later in the southernmost provenances (Blefjell and Hafnarskogur) than in the provenances originating from farther north (Table 7.1). The longer observation series (1994–2002) from Melbu confirmed that the relative date of bud burst of each provenance was consistent over years (Table 7.1), despite the large annual variation (up to 3 weeks) in actual dates of bud burst. The oceanic Melbu provenance showed later bud burst in all the transplantation sites than the more continental Abisko and Kilpisjärvi provenances of approximately the same latitudinal origin. However, another oceanic provenance (Hammerfest) came into leaf earlier than, e.g., the more continental Kevo provenances, but on the other hand, it was the northernmost of all the provenances, and there might be some kind of compromise in its response to these opposite trends (oceanity vs. northernness). In mountain birch, the timing of bud burst is genetically determined and is related to the length of the growth period in its natural habitat (Sulkinoja and Valanne 1987). Generally, *Betula* needs a chilling period of less than 10–12 °C for bud break, and this requirement decreases significantly with increasing latitude of origin (Myking and Heide 1995), but increases with oceanity (Leinonen 1996; Myking 1999). Normally, the chilling period needed in birch for the start of new activity in spring is long enough all over Fennoscandia, and Myking and Heide (1995) conclude that there is little risk of a chilling deficit in birch under Scandinavian winter conditions, even with a climatic warming of 7–8 °C. The timing of bud burst is dependent on temperature sum in spring, and the threshold value of temperature sum for bud burst varies among birch provenances (Sulkinoja and Valanne 1987; Billington and Pellham 1991).

In contrast to the results obtained from the Melbu, Kilpisjärvi and Pallasjärvi sites, the southernmost provenance (Rovaniemi) in the Kevo transplant sites showed slightly earlier bud burst than the more northern ones (Fig. 7.3). In contrast, some of the higher-elevation provenances (Ylläs and Kiilopää) had delayed bud burst compared to the lower-elevation ones of approximately the same latitudinal origin. These results are in accordance with the results of Sulkinoja and Valanne (1987) who also found that mountain birch provenances from northern Lapland required greater thermal sum for bud break than those from southern Lapland – the same was observed for high-altitude provenances compared to low-altitude ones. The reason for the later bud break in the more northern and higher-elevation provenances in

Table 7.1. Mean date of bud burst for each provenance in Melbu, Kilpisjärvi and Pallasjärvi transplantation sites in 1994, as well as relative date of bud burst and relative senescence timing index in Melbu from 1994 to 2002

			Transplant Garden						
	Latitude N	Altitude (m a.s.l.)	Melbu Mean date of bud burst in 1994		Kilpisjärvi	Pallasjärvi	Melbu Relative date of bud burst[a]		Melbu
Provenance				SE				SE[b]	RSTI[c]
Hammerfest	70°39'	70	17 May	0.27	18 June	09 June	–2.7	0.38	–1.0
Kevo, low alt.	69°46'	95	20 May	0.81	23 June	10 June	–0.4	0.13	–0.7
Kevo, high alt.	69°46'	280	18 May	0.40	20 June	10 June	–1.4	0.23	–1.6
Utsjoki, Paddaskaidi	69°56'	330	19 May	0.39	N.D.	N.D	–0.9	0.22	–2.7
Melbu	68°31'	40	21 May	0.52	27 June	13 June	1.6	0.40	0.8
Kilpisjärvi	69°04'	510	19 May	0.19	19 June	10 June	–0.3	0.20	–2.2
Abisko	68°22'	360	19 May	0.43	20 June	11 June	–0.9	0.31	–0.3
Hafnarskogur	64°31'	20	22 May	0.51	13 July	14 June	1.7	0.30	2.6
Narssarssuaq	61°10'	70	21 May	0.49	N.D.	N.D.	1.7	0.30	2.4
Blefjell	59°47'	750	23 May	0.50	20 July	15 June	1.7	0.43	2.7

N.D., No data

[a] The difference (days) from the annual average over all provenances from 1994 to 2002

[b] Based on interannual variation

[c] Relative senescence timing index 1994–2002 (see CD for explanation)

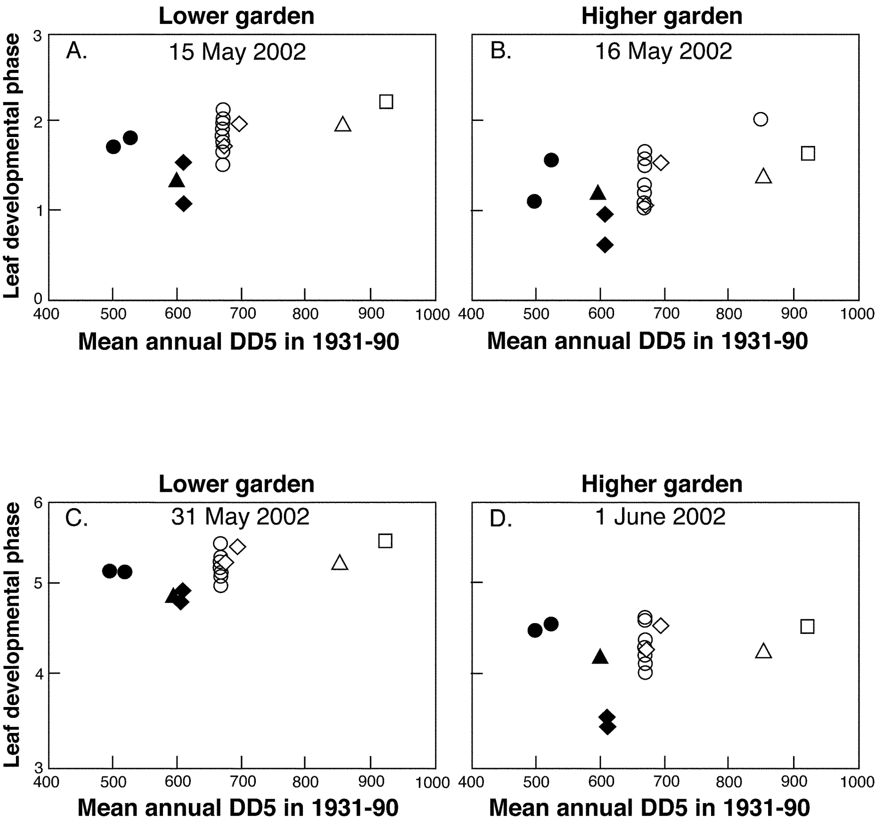


Fig. 7.3. Mean phase of bud burst and leaf development for different provenances in Kevo low-elevation and high-elevation garden at two different observation dates. The *horizontal axis* shows the estimated annual thermal sum (degree days over the base +5 °C; $\mathrm{DD5} = \sum_{n=1}^{n}\left(t_m - 5\right)$, where DD5 is the accumulated temperature sum, *n* is the total number of days with a mean temperature higher than threshold, and t_m is the mean temperature of the *n*th day) of the original habitat of each provenance. Leaf developmental phase was determined using an index from 0 (dormant bud) to 6 (leaf blade open and petiole clearly discernible). Each *dot* represents a mean value for a progeny. *Symbols with the same shape* represent provenances of approximately the same latitude (*square* 66°30′–67° N, *triangle* 67°15′–67°45′ N, *diamond* 68°–68°30′ N, *circle* 69°30′–70° N); *open symbols* represent low- or moderate-elevation and *filled symbols* high-elevation (tree-line) provenances

northeastern Fennoscandia is probably the greater influence of *B. nana* genes in these provenances as a result of introgressive hybridization (Sulkinoja and Valanne 1987; Myking 1999). Moreover, Senn et al. (1992) observed that short and small-leaved mountain birches had later bud burst than taller and bigger-leaved birches. This also suggests the greater influence of *B. nana* in the former. Indeed, the Kiilopää provenance, which had late bud burst, had clearly smaller leaves than the other provenances. Bud burst occurred slightly later in trees growing in the higher garden than in those growing in the lower garden due to the delayed attainment of the threshold value for thermal sum to bud break.

Phenology is an important tool in studies of climate change as historically documented by phenological data (Linkosalo 2000; Wielgolaski and Inouye 2003), and it can be used to demonstrate the regional/geographical differences in global change impacts (Høgda et al. 2002; Kozlov and Berlina 2002). However, it would be premature to present a predictive model of (mountain) birch bud burst under different climatic scenarios over the whole of Fennoscandia. In fact, Karlsson et al. (2003) analysed mountain birch phenology (bud break) in Abisko (1956–2002) and Kevo (1981–2002), and found that different models showed the best performance with Abisko vs. Kevo data: a simple degree-day accumulation model based on daily mean temperatures resulted in the best predictions in Kevo, while a more complex model was best in Abisko. Furthermore, there seem to be differences in the threshold temperatures for degree-day accumulation in birch studies from different areas (cf. Wielgolaski 1999; Karlsson et al. 2003), and the importance of other factors like air humidity and precipitation for the timing of bud break (see Wielgolaski 2001) in northernmost Fennoscandia is poorly understood. Therefore, studies in transplant gardens like those presented in this chapter, also clearly demonstrate how important the genetic background and local adaptations are in controlling birch phenology and growth (see also Chap. 5).

7.3.3 Autumn Phenology

With respect to leaf senescence and leaf fall of birch seedlings in the Melbu and Pallasjärvi transplantation sites in the second year after planting, the southernmost provenances (Blefjell and Hafnarskogur) showed delayed leaf yellowing and fall compared to the more northern ones (Fig. 7.4). A follow-up monitoring (1994–2002) in Melbu verified the consistency in the order of leaf senescence among different provenances (Table 7.1: RSTI). These results are in accordance with earlier results obtained from phytotron studies using northern and southern mountain birch provenances (Nilsen and Wielgolaski 2001). In addition, the oceanic Melbu provenance had later foliage senescence than the more continental provenances of approximately the same latitudinal origin. The high-altitude provenances (Paddaskaidi, Kevo high-altitude and

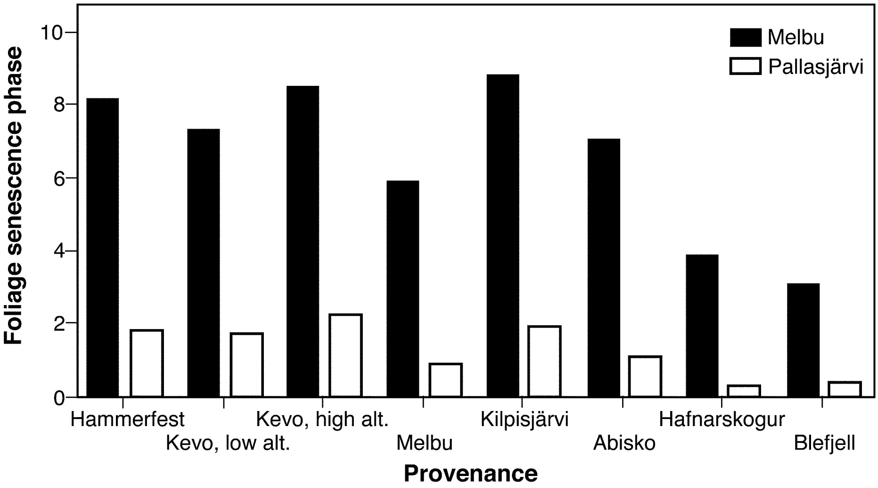


Fig. 7.4. Mean phase of foliage senescence (autumnal coloration) and abscission for different provenances in Melbu and Pallasjärvi transplantation sites on 10 September 1994. Determination of autumnal coloration and fall of leaves was made using the following scale: *0* all leaves green; *1* first signs of yellowing; *2* less than 25 % of the leaves yellow; *3* 26–50 % of the leaves yellow; *4* 51–75 % of the leaves yellow; *5* 76–99 % of the leaves yellow; *6* all leaves yellow; *7* <50 % of the leaves fallen; *8* 51–75 % of the leaves fallen; *9* 76–99 % of the leaves fallen; *10* all leaves fallen

Kilpisjärvi) had earlier leaf yellowing and leaf fall than the lower-altitude provenances. These results clearly indicate that there are genetic differences among latitudinal and altitudinal ecotypes of mountain birch in the timing of autumnal coloration and leaf fall, and that these differences are related to the length of the growing season in their natural habitats (cf. Sulkinoja and Valanne 1987). At the oceanic Melbu transplantation site, foliage senescence and leaf fall were much earlier than in the more continental Pallasjärvi site. Since bud burst also took place earlier at the Melbu site than in the Pallasjärvi site (Table 7.1), the difference in the timing of leaf yellowing and leaf fall between the sites might be partially caused by the genetically determined length of the growth period in different provenances.

In general, also in Kevo transplant gardens, the southernmost low-altitude provenances showed a delay in foliage senescence, while the foliage of the northernmost high-altitude provenances turned yellow early (Fig. 7.5). There was a nice correlation between the foliage senescence index (chlorophyll disruption rate) and the thermal sum of the original habitat of a provenance, showing that the greater the mean maximum thermal sum of the habitat, the more delayed the senescence process is (Fig. 7.5). Together with the results obtained from the bud burst observations (Fig. 7.3), these results suggest that the low-altitude provenances from southern Lapland are genetically adapted

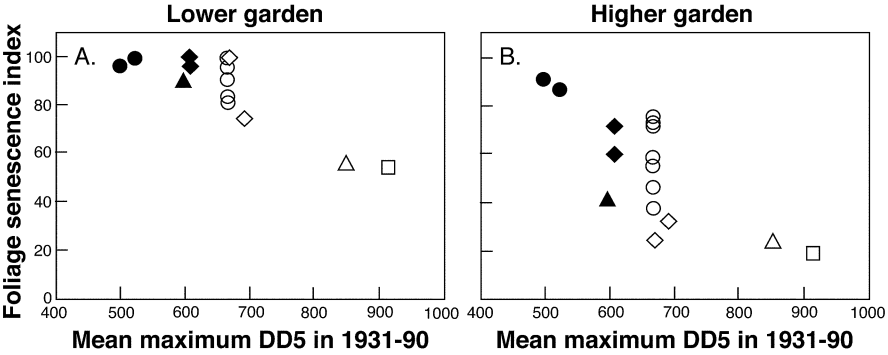


Fig. 7.5. Foliage senescence index (%) for provenances in the Kevo low-elevation and high-elevation garden in mid-September 2000, as a function of the estimated thermal sum of the original habitat of each provenance. Senescence index was determined by estimating visually the yellowing rate of the leaves and the rate of leaf fall. The senescence index is a relative measure of chlorophyll disrupted (0–100 %) in foliage at the observation date. Each *dot* represents a mean value for a progeny. See legend to Fig. 7.3 for the explanation of symbols

to a longer growth period than the more northern and higher-altitude provenances (Sulkinoja and Valanne 1987). Surprisingly, senescence of foliage took place earlier in the lower garden than in the higher garden, although it was expected to occur earlier under high-altitude conditions due to more rapid lowering of temperature in autumn. The delayed senescence of foliage in the higher garden compared to that in the lower garden was most probably due to the more favourable soil conditions in the former. In accordance with this, Nilsen and Wielgolaski (2001) found in their phytotron studies with southern and northern mountain birch provenances that fertilization greatly delayed the leaf senescence process in mountain birch seedlings, and this was seen especially in northern provenances. The results presented here also suggest that, in addition to the strong influence of temperature and light conditions on the phenology of mountain birch, edaphic factors (soil fertility and soil moisture) also play an important role in determining these phenomena.

7.3.4 Growth Forms and Growth Rates

Mountain birch is typically bush-like in shape; this polycormic birch type is widely distributed and concentrated in the continental part of the Fennoscandian subarctic region (Hämet-Ahti 1963). Clearly distinguishable from the polycormic birch type is the more maritime monocormic mountain birch (Kallio and Mäkinen 1978), which normally also grows under better nutrient conditions (Wielgolaski and Nilsen 2001; see also Chaps. 1 and 12). In northernmost Finland this birch type usually occurs at a high elevation (cf. Paddaskaidi provenance), where it forms a sparse, park-like tree-line forest. On the other hand, the monocormic birch type is also found in some places at the sea coast where it may form a very dense population. There is still one birch type which clearly differs from the former ones; it may have a few-meters-long trunk which creeps close to the ground. This creeping or procumbent birch type (*B. pubescens* ssp. *czerepanovii* var. *appressa*; Kallio and Mäkinen 1978) was described first in the Kiilopää area in eastern central Lapland (cf. Kiilopää provenance). It is adapted to grow at very high altitudes and the creeping mode of growth may be an adaptation to the windy and cold winter climate; it is protected against wind and cold by just a thin layer of snow due to its procumbent habit. However, the growth form of the half-sibling offspring in the Kevo transplant gardens is not always identical to that of its mother tree, suggesting that the growth form may not be strictly the outcome of ecotypic differentiation, but partially the result of phenotypic adjustment to the prevailing environmental conditions. Alternatively, the creeping type growing at a high elevation may have hybridized with a polycormic and more upright birch type growing at lower elevations resulting in an intermediate type (Kallio et al. 1983).

In many tree species, growth is retarded after transplantation, irrespective of whether the transfer is directed southwards or northwards from the original habitat of a tree (e.g. Carter 1996). Furthermore, in *B. pubescens* and *B. pendula*, a long-distance transfer from the original habitat causes growth retardation (Eriksson and Jonsson 1986). This was very clearly seen in the southernmost provenances in the Melbu, Kilpisjärvi and Pallasjärvi sites (Fig. 7.6) and to some extent also in Kevo gardens (Fig. 7.7). The slow growth rate of the southernmost provenances was most probably due to transplantation stress caused by the long latitudinal distance between their original habitats and transplantation sites. Eriksson and Jonsson (1986) have concluded that, since a provenance is adapted to a given photoperiod in its natural habitat, transplantation to new photoperiodic conditions may play an important role in this slackening of growth. The shortening of the photoperiod towards the end of the summer has been found to be the key factor in determining the cessation of growth in northern plants (Partanen and Beuker 1999). However, the long-lasting growth of southern provenances transplanted further north often causes a weaker hardening of the shoots by the end of the summer, and hence, they are often exposed to frost damage during winter and spring. Indeed, the southernmost provenance in Kevo gardens had clearly visible injuries, indicating that it was suffering from long-distance transfer from its original habitat. This is probably also one reason for the low survival rate (see Fig. 7.2) of the southern provenances of *B. pubescens* transplanted farther north.

Using reciprocal transplantations with *B. pendula* and *B. pubescens* provenances between two different types of habitats – heath and bog, Davy and Gill

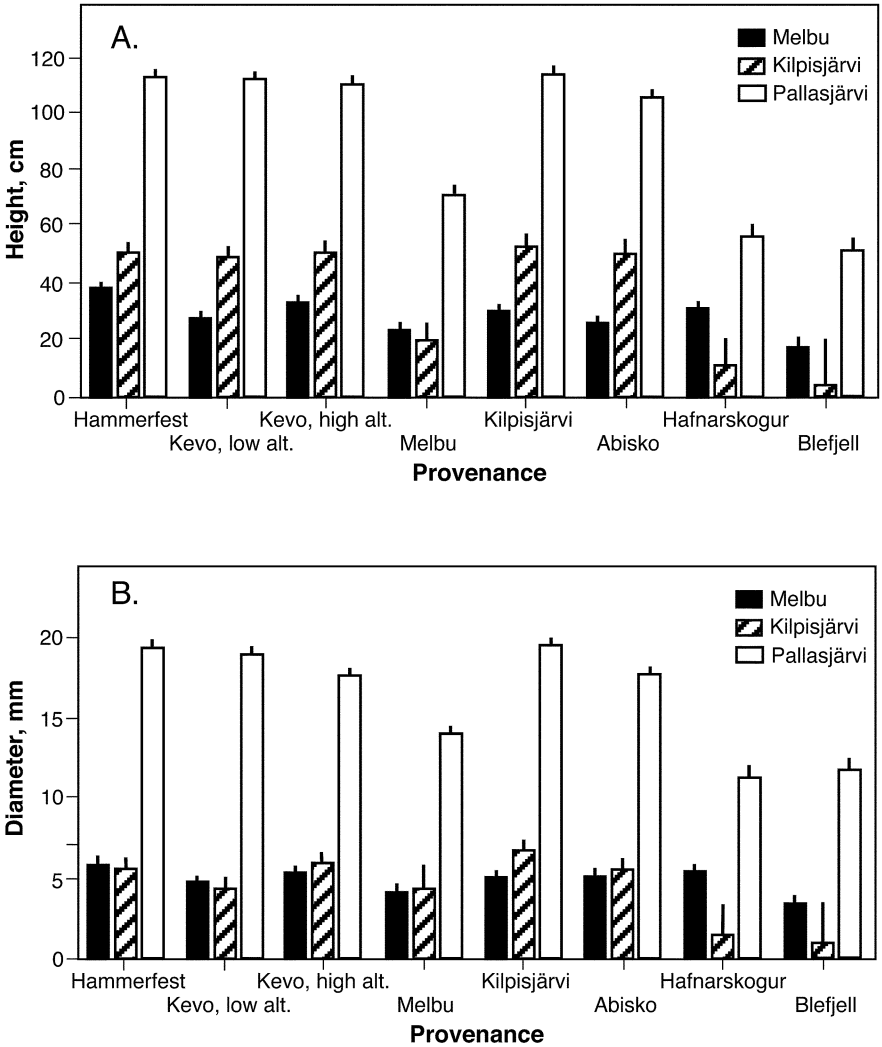


Fig. 7.6. Mean height (cm) and base diameter (mm) for different provenances in Melbu (n=101–129 for each provenance), Kilpisjärvi (n=46–82 for each provenance, except 25–31 for Melbu provenance, and 3–10 for Hafnarskogur and Blefjell provenances) and Pallasjärvi (n=109–123 for each provenance, except 67–70 for Hafnarskogur and Blefjell provenances) in late summer of the second year after planting. The *narrow bars* show SE

(1984) observed that the growth of seedlings was highly dependent on the edaphic factors of the habitat. Fertilization also promotes growth in *B. pubescens* clones (Lappalainen et al. 2000) as well as in mountain birch seedlings (Weih and Karlsson 1999) and older trees in their natural habitats (Sveinbjörnsson et al. 1992) and in transplantation gardens (Ruohomäki et al. 1996). In particular, the Melbu and Kilpisjärvi transplantation sites are relatively

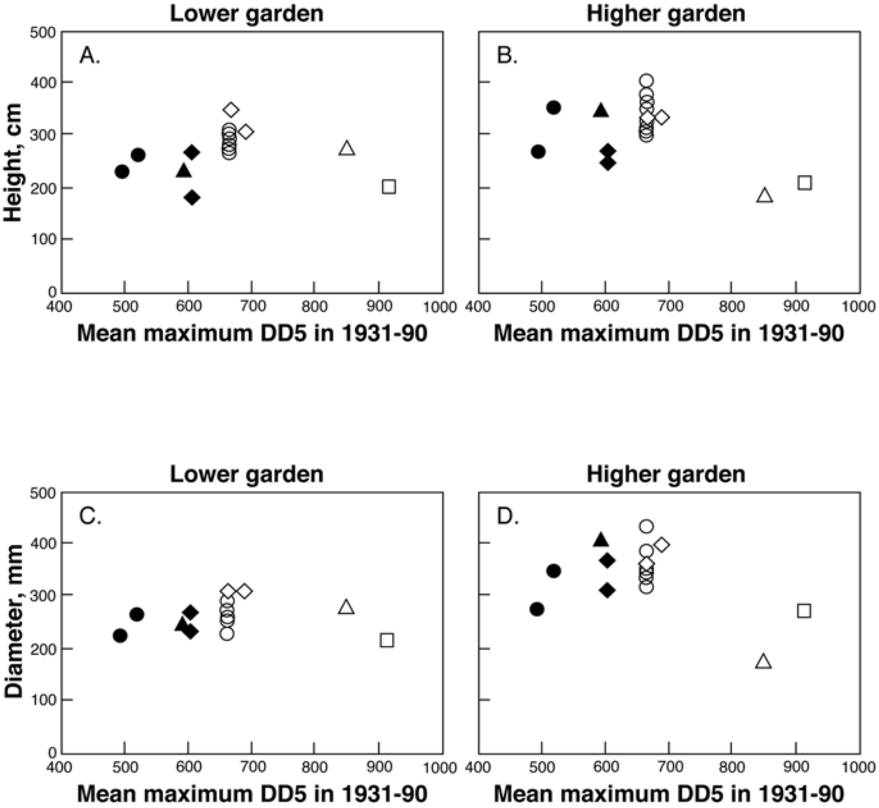


Fig. 7.7. Mean height (cm) and base diameter (mm) for different provenances in the Kevo low-elevation and high-elevation garden in summer 2000, as a function of the estimated thermal sum of the original habitat of each provenance. Each *dot* represents a mean value for a progeny. See legend to Fig. 7.3 for explanation of symbols

nutrient-poor, suggesting that the differences in the growth responses of the seedlings between these sites (Fig. 7.6) were mainly determined by other than edaphic factors. In general, the height growth of the seedlings was less in the oceanic Melbu site than in the more continental Kilpisjärvi and Pallasjärvi sites. Only the southernmost provenances (Blefjell and Hafnarskogur) succeeded markedly better in the Melbu site than in the high-altitude Kilpisjärvi site, and there was no clear difference in the growth of the oceanic Melbu provenance between these two sites. Therefore, highly oceanic conditions seemed to reduce the growth of most provenances compared to more continental conditions. Furthermore, the height of the seedlings in all provenances was markedly greater in the lower-altitude and still more continental Pallasjärvi than in the Kilpisjärvi site. On the other hand, there were no such big differences in the diameter growth of most provenances between the Melbu and Kilpisjärvi sites. The seedlings generally seemed to be more robust under the oceanic conditions than under the more continental and higher-altitude conditions. When considering the growth responses of different provenances between the Kevo transplant gardens, it was obvious that both height and diameter growth of most provenances were increased in the higher garden due to better nutrient and moisture conditions (Fig. 7.7). Only one provenance, having a relatively southern origin, showed a marked reduction in height and diameter growth under high-altitude conditions. Therefore, despite high-altitude conditions, many lower-latitude and lower-altitude provenances were able to benefit from the better soil conditions. Hence, edaphic factors may be as important as climatic factors in determining the performance of northern *B. pubescens* trees.

Ruel and Ayres (1996) observed that when the seedlings of *B. papyrifera* were transplanted to a higher elevation their root-to-shoot ratio increased and hence, the growth of the shoot was retarded. Seedlings are thus able to adjust to cold and nutrient-poor conditions by allocating more resources to root growth. In the present study, there might also be differences in the relative allocation of resources to root growth between different sites. In particular, the soil conditions of the Kevo gardens differed markedly from each other, the lower garden having much poorer soil than the higher garden. Therefore, it might be that the retarded shoot growth of the saplings grown in the lower garden compared to the growth of the saplings in the higher garden was partially due to relatively greater root growth at the expense of shoot growth in the former.

Using a reciprocal transplantation procedure, Weih and Karlsson (1999) showed that there are genetically determined differences in the growth rates and in the reaction norms of the growth between mountain birch ecotypes of different altitudinal origin. Seedlings belonging to a lower-altitude population were able to benefit from temperature rise and the addition of fertilizer by accelerating growth, but seedlings belonging to higher-altitude population experienced no such impact on growth. Higher-altitude seedlings had greater growth rates at low temperatures and higher leaf nitrogen concentration than lower-altitude seedlings (see also Chap. 5). High leaf nitrogen concentration is often an indication of a high leaf photosynthetic rate (e.g. Karlsson 1991). Weih and Karlsson (1999) concluded that the great efficiency of nitrogen metabolism and photosynthesis are adaptations to the short growing season of high-altitude habitats. With respect to provenances grown in the Kevo transplant gardens, Ovaska (1988) found that the saplings of high-altitude provenances (Kiilopää and Paddaskaidi) had greater leaf photosynthetic rates per unit leaf area than those of lower-altitude provenances. Therefore, ecotypic differentiation can also clearly be seen in elevational mountain birch populations in terms of physiological characteristics.

7.4 Conclusions and Future Prospects

The results presented in this chapter suggest that mountain birch provenances are phenotypically plastic in their response to different environmental conditions with the exception of the southernmost provenances which suffered from the long-distance transfer to the north, especially to high-altitude conditions in Kilpisjärvi. Northern and high-altitude provenances showed clearly better seedling growth in Pallasjärvi (warmer growing seasons) than near their site of origin, suggesting that although the northern mountain birches have adapted to harsh growing conditions, they have considerable capacity to respond positively to possible increasing temperatures. However, birch provenances from southern Lapland might have difficulties to adapt to different photoperiods and shorter growing seasons at higher latitudes, with the subsequent increased risks of frost damage. The results presented here also highlight the importance of edaphic factors in determining the phenological and growth responses of mountain birch. Better nutrient and moisture conditions of the soil delay autumnal coloration and improve growth of most mountain birch provenances, and this happens even in low-elevation provenances under high-elevation conditions.

A better understanding of the factors controlling the phenology of birch is urgently needed before we can reliably predict the ecological impacts of climate change on northern birch forests. Linkosalo et al. (2000) stressed that there is increasing evidence that light conditions also play a role in the timing of spring phenology of *Betula* spp. According to Myking (1999), long photoperiods significantly reduce the time to bud burst in partly dormant buds, but not by the normal time of bud burst later in spring. The laboratory experiments by Karlsson et al. (2003) showed that the temperature sum required for bud burst in Abisko and Kevo declined from ca. 250 DD_2 (degree days above the threshold of +2 °C) in January to ca 100 DD_2 in May. The interplay of genetics, photoperiod, temperature, and possibly other environmental factors in determining the actual time of bud break is apparently quite complex. A combination of long-term monitoring, laboratory (and greenhouse) experiments, and transplant experiments at multiple field sites is obviously the most efficient way to test the various phenological models (e.g., Hänninen 1995, 1996; Linkosalo et al. 2000; Karlsson et al. 2003) and to fill the gaps in our understanding of climatic impacts on birch phenology and performance.

References

Beuker E (1994) Adaptation to climatic changes of the timing of bud burst in populations of *Pinus sylvestris* L. and *Picea abies* (L.) Karst. Tree Physiol 14:961–970

Billington HL, Pellham J (1991) Genetic variation in the date of budburst in Scottish birch populations: implications for climate change. Funct Ecol 5:403–409

Carter KK (1996) Provenance tests as indicators of growth response to climate change in 10 north temperate tree species. Can J For Res 26:1089–1095

Davy AJ, Gill JA (1984) Variability due to environment and heredity in birch transplanted between heath and bog. New Phytol 97:489–505

Eriksson G, Jonsson A (1986) A review of the genetics of *Betula*. Scand J For Res 1:421–434

Hagem O (1931) Forsök med vestamerikanske traeslag (German summary). Medd Vestl Forstl Forst 12:1–217

Hämet-Ahti L (1963) Zonation of the mountain birch forests in northernmost Fennoscandia. Ann Bot Soc 'Vanamo' 34:1–127

Hänninen H (1995) Effects of climate change on trees from cool and temperate regions: an ecophysiological approach to modelling of budburst phenology. Can J Bot 73:183–199

Hänninen H (1996) Effects of climate warming on northern trees: testing the frost damage hypothesis with meteorological data from provenance transfer experiments. Scand J For Res 11:17–25

Heikinheimo O (1949) Results of the experiments on the geographical races of spruce and pine (in Finnish with English summary). Comm Inst For Fenn 37:1–44

Høgda KA, Karlsen SR, Solheim I, Tømmervik H, Ramfjord H (2002) The start dates of birch pollen seasons in Fennoscandia studied by NOAA AVHRR NDVI data. In: Proceeding of IGARSS. 24–28 June 2002. Toronto, Ontario, Canada

Kalela A (1938) Zur Synthese der experimentellen Untersuchungen über Klimarassen der Holzarten. Comm Inst For Fenn 26:1–445

Kallio P, Mäkinen Y (1978) Vascular flora of Inari Lapland. 4. Betulaceae. Rep Kevo Subarct Res Stn 14:38–63

Kallio P, Niemi S, Sulkinoja M, Valanne T (1983) The Fennoscandian birch and its evolution in the marginal forest zone. Nordicana 47:101–110

Karlsson PS (1991) Intraspecific variation in photosynthetic light response and photosynthetic nitrogen utilization in the mountain birch, *Betula pubescens* ssp. *tortuosa*. Oikos 60:49–54

Karlsson PS, Bylund H, Neuvonen S, Heino S, Tjus M (2003) Climatic control of budburst in the mountain birch at two areas; consequences of changed climate. Ecography 26:617–625

Kozlov MV, Berlina NG (2002) Decline in length of the summer season on the Kola Peninsula, Russia. Climatic Change 54:387–398

Lappalainen J, Martel J, Lempa K, Wilsey B, Ossipov V (2000) Effects of resource availability on carbon allocation and developmental instability in cloned birch seedlings. Int J Plant Sci 161:119–125

Leinonen I (1996) A simulation model for the annual frost hardiness and freeze damage of Scots pine. Ann Bot 78:687–693

Linkosalo T (2000) Analyses of the spring phenology of boreal trees and its response to climate change. PhD Thesis, University of Helsinki, Department of Forest Ecology Publications 22. Helsinki, Finland

Linkosalo T, Carter TR, Häkkinen R, Hari P (2000) Predicting spring phenology and frost damage risk of Betula spp. under climatic warming: a comparison of two models. Tree Physiol 20:1175–1182

Magnesen S (1992) Injuries on forest trees related to choice of the species and provenances: a literature survey of a one-hundred year epoch in Norwegian forestry. Rep Skogforsk 7:1–46

Morgenstern EK (1996) Environmental influences and geographic variation. In: Morgenstern EK (ed) Geographic variation in forest trees. UBC Press, Vancouver, pp 45–89

Myking T (1997) Dormancy, budburst and impacts of climatic warming in coastal-inland and altitudinal *Betula pendula* and *B. pubescens* ecotypes. In: Lieth H, Schwartz MD (eds) Progress in biometeorology, vol 12. Phenology and seasonal climates I. Backhuys Publ, Leiden, pp 51–66

Myking T (1999) Winter dormancy release and budburst in *Betula pendula* Roth and *B. pubescens* Ehrh. ecotypes. Phyton 39:139–146

Myking T, Heide OM (1995) Dormancy release and chilling requirement of buds of latitudinal ecotypes of *Betula pendula* and *B. pubescens*. Tree Physiol 15:697–704

Nilsen J, Wielgolaski FE (2001) Effects of fertilization and watering on morphology in young mountain birch plants of different provenances – a pilot study. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and biosphere series, vol 27. UNESCO, Paris and Parthenon, New York, pp 71–76

Ovaska J (1988). Hieskoivun (*Betula pubescens* Ehrh.) pohjoisten provenienssien fotosynteettinen adaptaatio. MSc Thesis. University of Turku, Department of Plant Physiology, Turku, 31 pp

Partanen J, Beuker E (1999) Effects of photoperiod and thermal time on the growth rhythm of *Pinus sylvestris* seedlings. Scand J For Res 14:487–497

Reader RJ (1982) Variation in the flowering date of transplanted ericaceous shrubs in relation to their flowering season. J Biogeography 9:397–410

Ruel JJ, Ayres MP (1996) Variation in temperature responses among populations of *Betula papyrifera*. Silva Fenn 30:145–158

Ruohomäki K, Chapin FS III, Haukioja E, Neuvonen S, Suomela J (1996) Delayed inducible resistance in mountain birch in response to fertilization and shade. Ecology 77:2302–2311

Senn J, Hanhimäki S, Haukioja E (1992) Among-tree variation in leaf phenology and morphology and its correlation with insect performance in the mountain birch. Oikos 63:215–222

Sulkinoja M, Valanne T (1987) Leafing and bud size in *Betula* provenances of different latitudes and altitudes. Rep Kevo Subarctic Res Stat 20:27–33

Sveinbjörnsson B, Nordell O, Kauhanen H (1992) Nutrient relations of mountain birch growth at and below elevational tree-line in Swedish Lapland. Funct Ecol 6:213–220

Weih M, Karlsson PS (1999) Growth response of altitudinal ecotypes of mountain birch to temperature and fertilisation. Oecologia 119:16–23

Wielgolaski FE (1999) Starting dates and basic temperatures in phenological observations of plants. Int J Biometeorol 42:158–168

Wielgolaski FE (2001) Phenological modifications in plants by various edaphic factors. Int J Biometeorol 45:196–202

Wielgolaski FE, Nilsen J (2001) Coppicing and growth of various provenances of mountain birch in relation to nutrients and water. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and biosphere series, vol 27. UNESCO, Paris and Parthenon, New York, pp 77–92

Wielgolaski FE, Inouye DW (2003) High latitude climates. In: Schwartz MD (ed) Phenology: an integrative environmental science. Kluwer, Dordrecht, pp 175–194

8 Synthesis Section 1: A Dynamic Forest in a Changing Environment

P.S. Karlsson and F.E. Wielgolaski

Typically, European birches are a characteristic product of primary or human-induced secondary succession (Atkinson 1992). The mountain birch (*Betula pubescens* ssp. *czerepanovii*) is, however, an exception to this and forms a stable climax forest in north-western Europe. Mountain birch forests are found in parts of the world with relatively low human populations and long distances to major pollution sources (parts of the Kola peninsula are, however, an exception, Kozlov and Barcan 2000). These characteristics, in combination with the low productivity of this birch forest type (Chaps. 4, 5), may give the impression of a very stable environment where dramatic changes or events are rare. Several chapters in this (and the following) section(s) show that this is not the case. This system is highly dynamic at several different scales and aspects.

First, the mountain birch seems to be in a phase where its genome is changing relatively fast. It has repeatedly been suggested that in Iceland and continental Europe that the mountain birch formed through introgression between downy and dwarf birch (*B. pubescens* and *B. nana*; see e.g. Väre 2001), but the introgression hypothesis has only recently been confirmed by molecular techniques (Thórsson et al. 2001). The Greenland birch seems to be the result of similar introgression between *B. pubescens* and *B. glandulosa* (Sulkinoja 1990). The introgression probably contributes to large variability among individual trees in many characteristics and it seems plausible that introgression is an important factor that improves the fitness of the mountain birch in this particular environment. The dwarf birch successfully grows at considerably higher altitudes and latitudes than the downy birch (for distribution data on these species, see e.g. Chap. 1; Lid 1974; Hultén and Fries 1986). In fact, when comparing seedling growth performance under the climatic conditions prevailing in the mountain birch forest zone, the mountain birch outperformed downy and dwarf birch in several measures of growth (Karlsson et al. 2000). Similarly, near the tree line, mountain genotypes grow faster than lowland

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

genotypes, although growth was generally lower than at lower latitudes. In contrast, lowland genotypes perform better than tree line genotypes at low altitudes (Chap. 6). Furthermore, the mountain birch is less responsive to changed environmental conditions than more southern birches (Chap. 6), and high altitude genotypes of the mountain birch are less responsive than low altitude genotypes (Weih and Karlsson 1999). This indicates that with increasing altitude or latitude of the habitat, the mountain birch becomes increasingly stress-resistant (sensu Chapin et al. 1993). Thus, according the stress resistance syndrome (Chapin et al. 1993), plants which have adapted to stressful conditions are expected to show low growth rates, although they outperform non-stress-adapted plants under stressful conditions. Furthermore, they have a low plasticity in growth and allocation characteristics. Again, increasing introgression could be one factor behind this. In the long run, introgression possibly could result in the evolution of the mountain birch to a separate species. None of the research presented in this section has explicitly addressed the genetics or evolution of the birch. Introgression is, however, likely to be an important cause of much of the variability discussed in several chapters (mainly Chaps. 5–7).

Moreover, at the vegetation level, the mountain birch forests seem highly dynamic. Chapter 3 (see also Chap. 17) documents significant changes in the distribution of different plant communities over the last 40 years. For example, the dwarf cornel (*Cornus suecica*) forest type had a marginal distribution in the 1960s, whereas this vegetation type is currently widespread on riverbanks and other environments in the Máze study area (northern Norway). Similarly, meadow forests (characterised mainly by the Wood Crane's bill, *Geranium sylvaticum*) are most strongly affected by anthropogenic influence and have decreased. Currently, almost no undisturbed sites of this vegetation type remain in the study area. Furthermore, analyses of birch forest distribution based on remote sensing data (Chap. 4) show great changes in the extent of the birch forest in the Máze study area between 1961 and 2001. For example, the distribution of birch forests increased by more than 40 % during this period. The increase in dwarf cornel and bilberry forests (almost 400 %) was most marked. Similarly, in the Målselv area in northern Norway, the extent of the birch forest increased by 12 % from 1978 to 1999. In other areas a recent expansion of mountain birch forests to higher altitudes has also been documented (Chap. 1). These changes are often interpreted as a result of "climate change". There are many possible factors that could be proximate causes for the observed dynamics in vegetation cover and forest distribution. In addition to a changed climate, direct anthropogenic impacts on these ecosystems are changing in many areas (Chaps. 3–6 and Sect. 3). Changing positions of tree lines are, however, not a new phenomenon, tree-line positions have fluctuated considerably also in the past (Chap. 1).

In addition to the variability of many biological characteristics described above, the mountain birch forests inhabit a region with highly variable climatic, geological and edaphic conditions (Chaps. 1, 2). The soils vary at several different scales depending on bedrock, climate (mainly precipitation) and vegetation (Chap. 2). The soil types are mostly podzols and nanopodzols with a low pH and nutrient content (Chap. 2), which, together with a short, cool growing season, contribute to a low productivity of the mountain birch forests.

There are many results from short-term experiments showing the clear effects of temperature climate on many growth-related traits (Chaps. 5–7). Thus, the growth of both seedlings and mature trees shows a clear relationship to temperature climate. Similarly, bud burst is related to spring temperature, and growth is mainly dependent on summer and spring temperatures. Furthermore, winter conditions are important in affecting dormancy, winter hardiness and growth during the subsequent summer (see also Holmgren and Tjus 1996 and Tenow 1996 for observations where winter conditions cause damage in situ). However, no one, to our knowledge, has evaluated how the mountain birch forests may respond to long-term exposure to increased temperature. Several studies indicate that warming may not result in any persistent growth enhancement. Soil warming in a birch heath ecosystem has shown that higher soil temperatures result in increased nutrient availability, but only during a few years (Hartley et al. 1999). Some studies on other species and ecosystems indicate a similar pattern; modelling soil nutrient dynamics and forest growth of a birch forest in Alaska indicated a transient growth enhancement lasting for 20 years (Bonan and van Cleve 1992). Models of carbon balance of North American high-latitude forests indicate no effect of warming (Keyser et al. 2000). Analyses of annual ring widths of pines on the Kola Peninsula (Raspopov et al. 2002) also indicate only short-term growth enhancements of the warmer climate. Similarly, a review of long-term climate change tundra experiments indicates that, despite the cool growing conditions in this environment, warming treatment has relatively little effect on plant biomass and productivity (Shaver and Jonasson 1999). Thus, growth enhancements following increased temperature may last from a few years up to a few decades, but current results give no reason to expect long-term growth enhancements from increased temperature. Possibly a longer growing season caused by earlier bud burst in spring and later growth cessation in autumn could result in increased growth (Bergh et al. 2000, but see Keyser et al. 2000). In the long term, however, it is possible that, in parallel with the expansion to higher latitudes (see above), the mountain birch forest will be out-competed by coniferous trees at lower altitudes. With this scenario, the mountain birch forests respond to increasing temperatures by “migrating” to higher altitudes and will then continue to grow under similar temperature conditions as today. In such a case, no great changes in biomass and production of the mountain birch forest will be expected. However, there are observations indicating that the birch forests are becoming denser under moist and nutrient-rich conditions (Chap. 25) and are then avoided by reindeer (see Chap. 17).

In addition to large differences among individual trees within populations or sites (cf. above), there are substantial differences among provenances (Chap. 7). For example, mountain birch provenances grown in transplant gardens show marked differences in various characteristics, such as phenology (both leaf emergence in spring and leaf fall in autumn) and growth. Southern provenances (from ca. 60 and 65°N) showed the poorest performance when grown in the north (ca. 68–69°N). Oceanic conditions reduced growth more than inland conditions. Furthermore, inland genotypes appear to be less affected by transplantation to coastal conditions than vice versa. Apart from genotypic variation as reflected by long-distance transfer, the mountain birch is also phenotypically plastic and apparently able to adjust to great changes in growing conditions (Chap. 7).

It is difficult to discuss the ecology or productivity of the mountain birch forest without considering its main herbivores. Different herbivores, mainly insects and reindeer, are important in different areas (see Chaps. 9–12). These herbivores can have a profound impact on birch productivity (Chap. 5), as well as forest dynamics (Chap. 12). Massive defoliation can cause the death of mountain birch stems, which subsequently stimulates the production of new sprouts in multi-stemmed trees (cf. Chaps. 5, 12). This apparently drives a long-term cyclicity in the mountain birch forests. A periodicity of these cycles of roughly 100 years has been suggested for the Abisko area in northern Sweden (Chap. 12). The rare occurrence of stems older than 100 years in the Abisko area (Sonesson and Hoogesteger 1983) fits well with a 100-year cyclicity in stem mortality caused by *Epirrita* outbreak. It has even been suggested that the persistence of the mountain birch forest is dependent on this kind of perturbation (Haukioja and Koricheva 2000; Chap. 12). However, also in areas where outbreaks are rare due to low winter temperatures, such as the Máze-Kautokeino area (Chap. 3; Tenow and Holmgren 1987), old stems are rare. Thus, the longevity of the stems of this birch form is apparently relatively short even without insect outbreaks.

It is an open question as to how birch forest survival and productivity will be affected by herbivores in the future (cf. Chaps. 5, 6; Bylund 1999), or how logging strategies may influence productivity and use by herbivores (cf. Chaps. 21, 22). Short-term studies indicate that tree growth will increase with increasing temperatures, while results from long-term studies of other systems indicate that growth enhancements from a warmer climate may last for a few decades at the most. A shift of the mountain birch forests to higher altitudes, however, seems to have already started (Chap. 1). The marked intraspecific variation, both among individuals within sites and among provenances, in combination with a large phenotypic plasticity, may render mountain birch forests well suited to cope with a changing environment. Alternatively, the mountain birch forest will respond to a changed climate by moving to higher altitudes, thus maintaining its current "temperature niche".

Acknowledgements. Martin Weih provided constructive comments on the manuscript.

References

Atkinson MD (1992) Biological flora of the British Isles: *Betula pendula* Roth (*B. verrucosa* Ehrh.) and *B. pubescens* Ehrh. J Ecol 80:837–870

Bergh J, Flemberg S, Kinderberg J, Linder S, Räisinen J, Strömgren M, Wallin G (2000) Framtida klimatförändringar – tänkbara effekter på den svenska skogen. Fakta Skog, no 13, Swedish University of Agricultural Sciences, Uppsala, 4 pp

Bonan GB, van Cleve K (1992) Soil temperature, nitrogen mineralization, and carbon source sink relationships in boreal forests. Canadian J For Res 22:629–639

Bylund H (1999) Climate and the population dynamics of two insect outbreak species in the north. Ecol Bull 47:54–62

Chapin FS III, Autumn K, Pugnaire F (1993) Evolution of suites of traits in response to environmental stress. Am Nat 142:S78–S92

Hartley AE, Neil C, Melillo JM, Crabtree R, Bowles FP (1999) Plant performance and soil nitrogen mineralization in response to simulated climate change in subarctic dwarf shrub heath. Oikos 86:331–343

Haukioja E, Koricheva J (2000) Tolerance to herbivory in woody vs. herbaceous plants. Evol Ecol 14:551–562

Holmgren B, Tjus M (1996) Summer air temperatures and tree line dynamics at Abisko. Ecol Bull 45:159–169

Hultén E, Fries M (1986) Atlas of North European vascular plants: north of the Tropic of Cancer I–III. Koeltz Scientific Books, Königstein

Karlsson PS, Schleicher L, Weih M (2000) Growth and allocation patterns in three birch forms originating from habitats with different stress levels. Ecoscience 7:80–85

Keyser AR, Kimball JS, Nemani RR, Running SW (2000) Simulating the effects of climate change on the carbon balance of North American high-latitude forests. Global Change Biol 6 (Suppl 1):185–195

Kozlov MV, Barcan VS (2000) Environmental contamination in the central part of the Kola Peninsula: history, documentation and perception. Ambio 29:512–517

Lid J (1974) Norsk og Svensk flora. Det Norske Samlaget, Oslo

Raspopov OM, Kolström T, Shumilov OL, Kirtsideli IJ, Degachev VA, Lindholm M, Meriläinen J, Eggertsson O, Kasatkina EA, Kuzmin AV (2002) Global warming and regional tree-ring responses in the Kola peninsula, north-west Russia. The Finnish Forest Research Institute, Research Papers 862, pp 106–112

Shaver GR, Jonasson S (1999) Responses of Arctic ecosystems to climate change: results of long-term experiments in Sweden and Alaska. Polar Res 18:245–252

Sonesson M, Hoogesteger J (1983) Recent tree-line dynamics (*Betula pubescens* Ehrh. ssp. *tortuosa* (Ledeb.) Nyman) in northern Sweden. Nordicana 47:47–54

Sulkinoja M (1990) Hybridization, introgression and taxonomy of the Mountain birch in SW Greenland compared with related results from Iceland and Finnish Lapland. Meddr Grønland Biosci 33:21–29

Tenow O (1996) Hazards to a mountain birch forest – Abisko in perspective. Ecol Bull 45:104–114

Tenow O, Holmgren B (1987) Low winter temperatures and an outbreak of *Epirrita autumnata* along a valley of Finnmarksvidda, the "cold pole" of northern Fennoscandia. In: Alexandersson H, Holmgren B (eds) Climatological extremes in the mountains, physical background, geomorphological and ecological consequences. Dept Physical Geography, Uppsala University, UNGI-rapport 65, pp 203–216

Thórsson AT, Salmela E, Anamthawat-Jónsson K (2001) Morphological, cytogenetic and molecular evidence for introgressive hybridization in birch. J Hered 92:404–408

Väre H (2001) Mountain birch taxonomy and floristics of mountain birch woodlands. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man Biosphere Ser 27:35–46

Weih M, Karlsson PS (1999) Growth and nitrogen economy of mountain birch seedlings from different altitudes. Oecologia 119:16–23

Section 2

Herbivory

9 Forest Defoliation Risks in Birch Forest by Insects Under Different Climate and Land Use Scenarios in Northern Europe

S. Neuvonen, H. Bylund and H. Tømmervik

9.1 Introduction

Defoliation of mountain birch forests by insects is obviously the most important disturbance factor in these northern ecosystems. The main defoliators are geometrid moths like the autumnal moth, *Epirrita autumnata*, and the winter moth, *Operophtera brumata* (Tenow 1972). Outbreaks occur more or less regularly in the mountain birch forests and sometimes they cause widespread death of trees. For example, in northernmost Finland, *E. autumnata* defoliated birches in an area of about 1350 km^2 in the mid-1960s, and it was predicted that large parts of this area will change into treeless "tundra" (Kallio and Lehtonen 1973, 1975). Indeed, the recovery of the birch forest has been very slow, large areas remaining virtually treeless, even about four decades after the damage (Lehtonen and Heikkinen 1995; Kukkonen 2002; Sihvo 2002). This has not only decreased the possibilities for traditional livelihoods (reindeer herding, grouse hunting) in the area (Kallio and Lehtonen 1975), but it can also have strong effects on the biospheric feedbacks to hydrology and climate at the Taiga–Tundra ecotone (Harding et al. 2002). For other examples of the impact of insect herbivory on northern birch forests, see Nuorteva (1963, 1966). Chapter 12 describes in more detail the influence of herbivory by insects (and mammals) on different types of northern birch forests.

To understand the spatial and temporal variability of defoliation risks and the consequences of severe outbreaks under different scenarios, information from different sources should be compiled and synthesised: (1) historical and modern (e.g. remote sensing) data on temporal and spatial patterns of insect outbreaks (Tenow 1972; Neuvonen et al. 1999; Tømmervik et al. 2001); (2) ecological and ecophysiological knowledge about the birch–geometrid–natural enemy system and the effects of abiotic (climatic) factors on it (e.g. Nilssen and Tenow 1990; Tanhuanpää et al. 1999; Virtanen and Neuvonen 1999); (3) climatic data both from meteorological stations and their surroundings

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

(topographical variation; Virtanen et al. 1998); (4) knowledge about the role of human activity and management decisions (e.g. via the effects of ungulate grazing on birch growth, structure, and recovery after outbreaks) in this system.

This chapter summarises our current knowledge of the regional history of geometrid outbreaks on mountain birch in northernmost Finland, Norway and Sweden, as well as recent developments in the detection, monitoring and modelling of the outbreak risks under different climatic scenarios and their relationships to land use.

9.2 Geometrid Outbreaks on Birch in Fennoscandia

The population dynamics of certain insect species is often generalised and described with a few words, e.g. *E. autumnata* is referred to as a species showing cyclic dynamics with a period of 9–11 years (e.g. Neuvonen 1988). However, this is misleading because it hides striking regional differences in the population dynamics. In some areas along the Scandinavian mountain chain, the local populations really show rather regular cyclic dynamics (e.g. Hogstad 1997; Klemola et al. 2002), while it may be more common to find populations with fluctuations showing a strong periodic component, but widely varying amplitude (e.g. Bylund 1995). Furthermore, in the more continental areas in eastern Fennoscandia, the outbreaks do not occur at regular intervals (see Tenow 1972; Neuvonen et al. 1999). Finally, although *E. autumnata* is quite common over large areas it rarely, if ever, causes noticeable defoliation at more southern latitudes (Tenow 1972; Ruohomäki 1994; Tanhuanpää 2000; Klemola et al. 2002).

Operophtera spp. appear to have cyclic outbreaks in the birch forests on the western and north-western coast of Norway, where *Epirrita* outbreaks are more rare (Tenow 1972), although there seem to be no long-term monitoring data from this area. Moving inland from the Norwegian coast, both *Operophtera* spp. and *E. autumnata* show outbreaks with a strong periodicity, and in the middle of the Scandinavian mountain chain it is mostly *E. autumnata* that shows these periodic outbreaks (Tenow 1972; Andersson and Jonasson 1980; Bylund 1995; Hogstad 1997; Neuvonen et al. 1999). In the most continental parts of northern Fennoscandia, *Operophtera* spp. are rare and *E. autumnata* shows only irregular outbreaks (maybe two to three outbreaks per century on a regional scale) and some areas have no outbreaks at all (Tenow 1972; Tenow and Nilssen 1990; Neuvonen et al. 1999; Klemola et al. 2002). When outbreaks occur they are normally synchronous with those in the Scandinavian mountain chain (Tenow 1972). However, although large-scale synchrony of geometrid outbreaks in Fennoscandia is common, it does not always occur (see Tenow 1972; Klemola et al. 2002).

The geometrid outbreaks in birch forests also show local and topographical differences. When *Operophtera* spp. and *E. autumnata* outbreaks occur in the same area, the former occupies the more oceanic and lower altitude parts of the landscape (Hågvar 1972; Tenow 1972, 1975). In more continental areas, the *E. autumnata* outbreaks occur only in the middle and upper slopes of the valleys, while the birch forests in valley floors escape defoliation (Kallio and Lehtonen 1973; Tenow 1975). Stand age is apparently important as well: the same stands are not necessarily defoliated during successive outbreaks and heavy defoliation seems to be restricted to old birch forests (Bylund 1997; Ruohomäki et al. 1997).

As a background for more detailed studies at different areas in northern Fennoscandia, we summarise the history of major insect outbreaks in different focal areas (see map in the Preface):

Målselv: Both *Operophtera* spp. and *E. autumnata* show dynamics with a strong periodic component, the former at lower altitudes and the latter at higher altitudes;

Abisko: Fairly regular population peaks (cyclic outbreaks) of *E. autumnata* cause variable defoliation intensity on the upper parts of the slopes, while defoliation at lower altitudes has been rare (Tenow 1972; Bylund 1995). There was a major outbreak by *E. autumnata* in the 1950s on the southern side of lake Torneträsk and another by *O. brumata* on the northern side of the lake in the 1960s (Tenow et al. 2001);

Maze: No or very rare outbreaks of geometrid moths (Tenow and Nilssen 1990);

Vuotso: The area is mainly in the (northern boreal) coniferous forest zone, but the birches in the area at higher altitudes have experienced irregular outbreaks of *Epirrita autumnata* (Ruohomäki et al. 1997);

Utsjoki: Irregular defoliation at higher altitudes caused by *E. autumnata*. The last major outbreak was in the mid-1960s (some earlier damage occurred as well) when tree mortality was severe in about two thirds of the mountain birch forest area (Tenow 1972; Kallio and Lehtonen 1973). Smaller local outbreaks were observed in the mid-1990s (Neuvonen, pers. obs.). Recovery of the birch forests has been slow and poor, and today the defoliated areas are still visible in the landscape, mainly as open areas with rotten birch stumps either standing or lying on the ground (Kukkonen 2002).

9.3 Monitoring (Detecting/Quantifying) Insect Outbreaks in Mountain Birch Woodlands

Early reports of insect outbreaks in northern birch forests describe only qualitatively when and where defoliation has occurred, and they may give rough estimates of the area damaged (Tenow 1972 and references therein). In reality, the degree of defoliation is a continuous variable, the estimates have a considerable subjective component, and some defoliated areas may have been entirely missed, especially in remote areas. Consequently, better methods are needed for monitoring defoliation by insects in large areas with difficult access. Below, the applicability and usefulness of remote sensing in detecting and quantifying insect outbreaks in mountain birch forests are discussed.

A few previous studies have used remote sensing for the detection and mapping of geometrid outbreaks in Fennoscandia. The first study was carried out by Seppälä and Rastas (1980) in northern Finland. They successfully mapped the vast damaged area of 1210 km^2 of the mountain birch forest in Inari and Utsjoki (northernmost Finland) by using a Landsat Multispectral Skanner (MSS) scene taken 8 years after the damage. Since this study, the methods and sensors have been improved significantly (Radeloff et al. 1999).

Tømmervik et al. (2001) achieved improved results using satellite remote sensing (Landsat TM) and comparison of images from different years, outbreak (1994) vs. non-outbreak (1990) years, in the detection of defoliated forests by caterpillars. Normalised difference vegetation index (NDVI) values of the two images were compared after calibration. To avoid natural barren zones and water, only areas with an NDVI >0.4 in 1990 were included in the comparison. Areas with possible caterpillar outbreaks were defined as those with an NDVI >0.4 in 1990 and with a decline of more than 5 % of the NDVI value to 1994, and the results were presented as maps. These data were combined with a vegetation cover map based on Landsat 5/TM image from 1990 (Johansen et al. 1995) and assessed against a "forest mask" (N250) from the State Mapping Authority in Norway. Table 9.1 summarises the attacked areas by vegetation type in Dividalen.

In the future, it will be necessary to refine the analysis by introducing more than just a single "attacked" class, i.e. to quantify the degree of defoliation. Before that is feasible, better algorithms to correct the various (e.g. atmos-

Table 9.1. The total and attacked (estimated by remote sensing) areas of major vegetation types in Dividalen in 1994, and the proportion of area attacked

	Total area (km^2)	Attacked area (km^2)	Attacked (%)
Meadow birch forests	27.6	3.5	12.7
(Mountain) birch forests	77.7	13.4	17.2
Dwarf shrub/dwarf birch, heath/scrub	252.0	23.5	9.3
Other vegetation types	454.1	4.0	0.9
Water, snow, glaciers and barren land	134.2	0.1	0.1
	945.6	44.5	4.7

pheric and topographic) sources of variation in the reflectance values as well as a better understanding of the relationship between NDVI (or other indices based on remote sensing) and birch foliage biomass are needed. Data from remote sensing (original biomass, degree of defoliation, vegetation type) combined with a digital elevation map and other data (e.g. stand age and distances from roads, households and tourist centres) can be very useful for land-use planning and management. Furthermore, this kind of data is essential for spatially explicit modelling of insect densities and/or defoliation risks.

9.4 Modelling the Outbreak/Defoliation Risks

9.4.1 Population Dynamics of Geometrid Moths

Figure 9.1 shows a graphic model of the lifecycle and population dynamics (and its relationships to main environmental factors) of the main geometrid defoliators in northern birch forests. Note that the relative importance of different environmental and biotic 'driving forces' varies between species as well as between areas within the distribution range of one species. The main biotic interactions take place during the larval and pupal stages. Larvae interact with (and are influenced by) their food plants (foliage quality and quantity) and their natural enemies (Fig. 9.1). Specialist enemies as well as induced changes in foliage quality (and quantity) can cause the time-delayed negative feedbacks necessary for cyclic population dynamics (Haukioja 1980; Haukioja et al. 1988; Neuvonen and Haukioja 1991; Bylund 1995; Kaitaniemi et al. 1999; Klemola et al. 2002).

Specialist parasitoids become very important at increased larval (and pupal) densities and their increase is the other important factor causing decline in geometrid densities after the peak. Generalist predators (like birds, small mammals, ants, spiders) cause an overall negative impact on the population growth rate of geometrids, and if this impact is strong enough, it can prevent the increase in geometrid populations to defoliating levels either locally (Laine and Niemelä 1980; Karhu and Neuvonen 1998) or regionally (Tanhuanpää et al. 1999, 2001). The shift in dynamics from cycles or less regular outbreaks to stability is probably caused by a higher predation pressure from generalist enemies in southern than in northern Fennoscandia (Tanhuanpää 2000; Klemola et al. 2002).

There are also modelling attempts with respect to the *E. autumnata*–parasitoid interaction (Tanhuanpää et al. 2002), but to our knowledge there are no published models trying to combine the interactions of geometrids with both their host plant (foliage quality and quantity) and natural enemies. Furthermore, the few existing models of defoliator population dynamics do not nor-

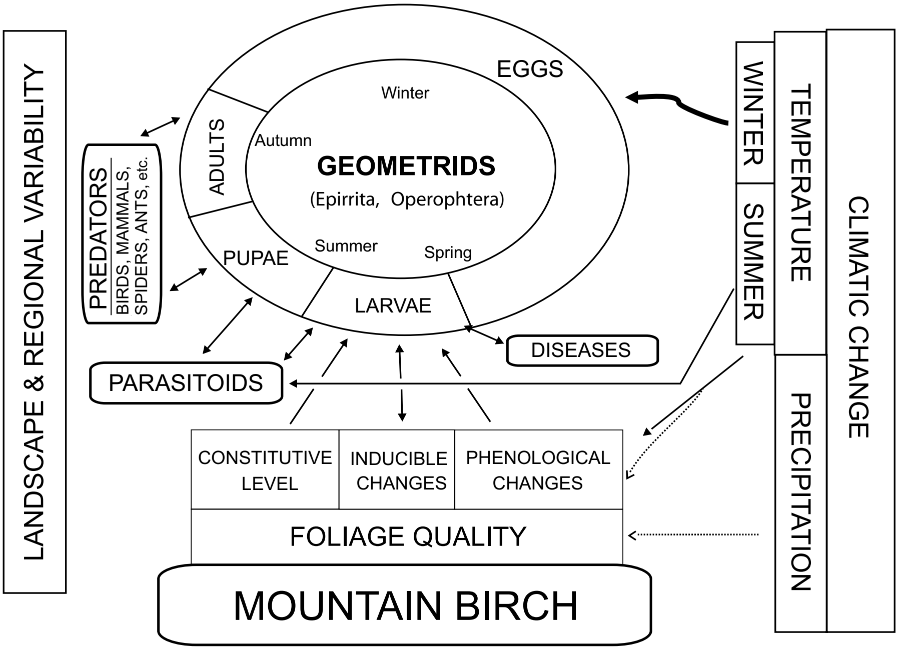


Fig. 9.1. A graphic model describing the annual life cycle of defoliating moths in northern birch forests, and the most important relationships/interactions between abiotic and biotic environmental factors and the different life stages of the moths. See text for details and explanation. There can be both rapid and delayed inducible changes in foliage quality as a response to insect attack. (Neuvonen and Haukioja 1991)

mally consider spatial variability in densities and demographic processes (cf. Chap. 21). Realistic, spatially explicit models are urgently needed for insect populations showing drastic regional and local differences in population dynamics, like the geometrids in Nordic birch forests.

Considering only the biotic interactions would lead to "idealised population dynamics" which can be regionally different (cf. Tanhuanpää 2000; Klemola et al. 2002). In reality, however, the system is not in a 'vacuum' and abiotic environmental factors can disturb it either indirectly or directly (Fig. 9.1). Both abiotic and biotic factors cause temporal, regional and local/topographic differences in population dynamics and outbreak patterns. Low winter temperatures are the most important factor controlling the geometrid densities in northern and continental areas (see Chap. 12 and below) although summer temperatures may indirectly affect the interactions between different trophic levels. Temperatures during early summer may have some effect on foliage quality and there is a clear positive relationship between temperature and apparent parasitism of *E. autumnata* larvae (Virtanen and Neuvonen 1999). The direct and indirect effects of other environmental factors like precipitation and UV radiation on the performance of insects are poorly known (cf. Saikkonen and Neuvonen 1993; Suomela and Neuvonen 1997; Buck and Callaghan 1999; Neuvonen et al. 2001). One further way that spring and early summer temperatures may affect the performance of geometrid larvae is via phenological asynchrony between the hatching of larvae and birch bud break (Fig. 9.1; cf. Virtanen and Neuvonen 1999; Karlsson et al. 2003).

9.4.2 Modelling the Regional and Topographic Patterns in Outbreaks Risks

Virtanen et al. (1998) developed a GIS (geographical information system) model predicting the spatial variation in *E. autumnata* egg mortality in the vicinity of the Kevo Subarctic Research Station (256-km^2 study area) under different climate scenarios. The model is based on the known strict relationship between the mortality of *E. autumnata* eggs (the over-wintering stage) and minimum winter temperatures (from total mortality at temperatures below ca.–37 °C to very low mortality above ca. –34 °C; see Chap. 12; Nilssen and Tenow 1990) and on a phenomenon called temperature inversion. This means that minimum temperatures occur in calm periods with outgoing radiation when the cold air flows to and along valleys so that at the same time the temperature can be below –40 °C in the valley bottom, but above –25 °C on the upper parts of the valley slope (Tenow 1975; Tenow and Bylund 1989; Tenow and Nilssen 1990; Virtanen et al. 1998). Virtanen et al. (1998) estimated that assuming an increase of 3.6 °C in minimum winter temperatures by 2050 would lead to a considerable reduction in the area of birch forests protected by the cold winters in the Kevo area. However, this model cannot be directly applied to different parts of the mountain birch zone because of the high regional variation in environmental conditions. To extend the model over larger regions, we have collected, within the HIBECO project, information about topographical variation in winter minimum temperatures from different areas: (1) coast of Norway NW of Abisko; (2a) Abisko (Sweden) – southern side of Torneträsk; (2b) Abisko – northern side of Torneträsk; (3) Maze (Norway); (4) Vuotso (Finland); (5) Utsjoki (Finland); cf. map in Preface.

The study areas differ with respect to oceanity/continentality, absolute altitude above sea level, and topographical variability. The northwestern coast of Norway and the Abisko region are mountainous with over 1000-m altitudinal variation, although birch forests occur only at the lower end of this range (Fig. 9.2). The birch forest limit in the Abisko area is about 300 vertical metres higher than near the western coast at similar latitudes. The landscapes in the Maze and Utsjoki areas have rather gently sloping fells with river valleys dominated by mountain birch forests with occasional pine stands, the range of altitudinal variation being clearly less than in the previous areas (Fig. 9.2). The Vuotso area shows the least topographical variabil-

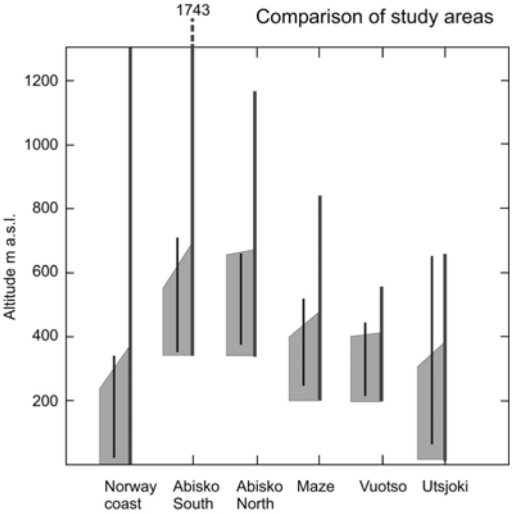


Fig. 9.2. Topographic characteristics of different study areas (see map in Preface). The *narrow bars* at the right side of each column show the total altitudinal range in each area. The *wider bars* show the extent of forests (mainly mountain birch). The *narrow bars* in the middle of each column show the range of altitudes where we had temperature loggers to monitor winter temperatures

ity and the lower altitudes are dominated by coniferous (Taiga) forests. The Conrad continentality index varies from below 20 near the coast of Norway, about 30 in Abisko and Utsjoki to above 34 in the Vuotso area (Tuhkanen 1984). See Chapter 1 for examples of monthly and annual mean temperatures and precipitation sums.

To characterise temporal variability in minimum winter temperatures (MWT), Fig. 9.3 shows the MWT at Kevo during 1962–2001, and also minimum, median and maximum values for the MWT during 1961–1990 at meteorological stations in or near the different study areas. There is high annual variability in MWTs and the difference between the extreme years in the Kevo time series (Fig. 9.3a) is 16 °C, suggesting that the detection of any significant trends (if any exist) in this parameter would require much longer data series. The variation in MWT is of the same magnitude in the other study areas also, with the exception of the outer coastline of northern Norway, where it is about 7 °C (Fig. 9.3b). In most of Norway, the MWT always stays above –20 °C, but at Finnmarksvidda (Maze) it remained below –35 °C during 1961–1990 (see also Tenow and Nilssen 1990). In the more continental sites with long-term meteorological data (Fig. 9.3b), the median MWT was below the critical limit for *E. autumnata* egg survival (cf. Chap. 12). However, the meteorological stations are often situated close to the valley floors and consequently we need data from their surroundings to characterise MWTs over the whole landscapes.

During our study winter 2000–2001, there were clear differences in the MWT and in the relationship to altitude between the study areas (Fig. 9.4). In the most oceanic area, there were no signs of temperature inversions and the

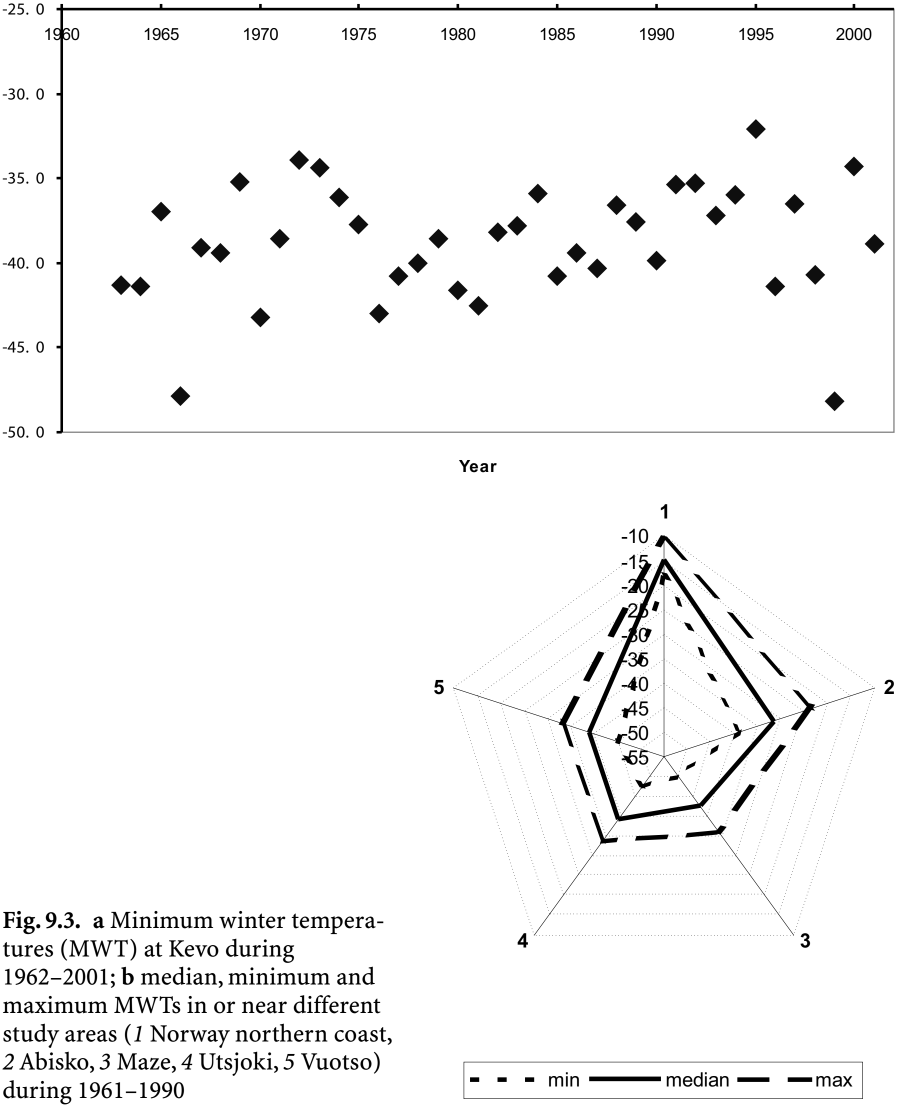


Fig. 9.3. **a** Minimum winter temperatures (MWT) at Kevo during 1962–2001; **b** median, minimum and maximum MWTs in or near different study areas (*1* Norway northern coast, *2* Abisko, *3* Maze, *4* Utsjoki, *5* Vuotso) during 1961–1990

MWT remained much above the critical temperature for *E. autumnata* egg mortality. The areas on the northern vs. southern side of the lake Torneträsk (near Abisko) showed interesting differences despite being at the same altitude. During the study winter, the MWT did not reach the critical level for *E. autumnata* egg mortality in the northern area while the critical temperatures were reached at the lowest site in the southern area. In the most continental study areas (Maze, Utsjoki and Vuotso), the MWT showed much topographical variation on both sides of the critical temperature for *E. autumnata* egg mortality.

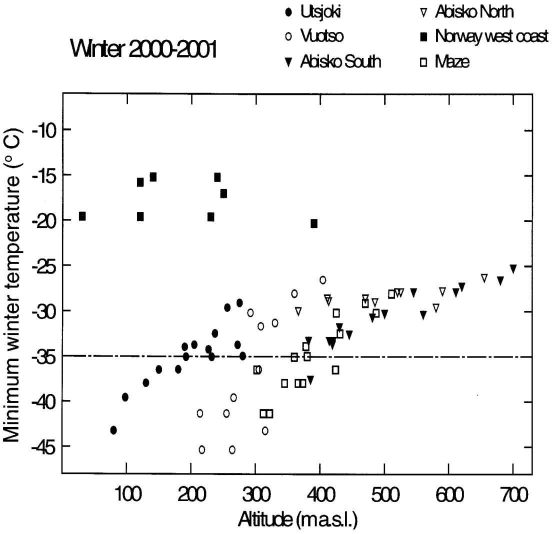


Fig. 9.4. The relationship between altitude and minimum temperature during winter 2000–2001 in different study areas (see Fig. 9.2 and map in Preface)

Both the variability in topography–minimum winter temperature relationships (see above) and the geographical differences in the relative importance of different factors for geometrid population dynamics must be considered in a defoliation risk model for the Fennoscandian mountain birch forests (cf. Tenow 1996; Neuvonen et al. 1999; Niemelä et al. 2001).

9.5 Forest Defoliation Risks Under Different Climatic Scenarios and Their Relationships to Land Use

It seems probable that climatic change can have major effects on northern animal populations and defoliation risks in mountain birch forests. Given the regional variation and large uncertainties in long-term climate scenarios, we can take only the "what if" approach. Note that the North Atlantic area is problematic for climatic modelling – different general circulation models show strongly varying results (Saelthun and Barkved 2003). However, the recent regional models indicate the following general tendencies: air temperature increase of about 0.35–0.4 °C per decade (about twice the increase in winter as in summer) and precipitation increase of 1.5–2 % per decade (also larger increase in winter/autumn than in summer; Saelthun and Barkved 2003; see also Chap. 1). Below we consider the potential effects of warmer summers and winters separately.

The estimation of the impacts of climatic change on birch defoliation risks is not made easier by the situation that warmer winters and warmer summers may have opposite effects. The increased defoliation risk associated with warmer winters has been described above. On the other hand, warmer summers can decrease the defoliation risk by lowering the foliage quality (Niemelä 1980; Virtanen and Neuvonen 1999) and enhancing the efficacy of natural enemies (Virtanen and Neuvonen 1999).

Increasing minimum winter temperatures will probably increase the birch defoliation risk in the more continental areas of northern Fennoscandia (e.g. Maze, Utsjoki, Vuotso) and it is possible that the clear periodicity (9–11 year intervals between peaks) typical for more oceanic mountain birch forests will extend to this area. In the oceanic parts of northern Fennoscandia (like the western coast of Norway), the minimum winter temperatures are already now above the critical limit for *E. autumnata* egg survival (Figs. 9.3, 9.4) and we do not expect any major changes in defoliation risk in this area (Neuvonen et al. 1999). However, changing oceanity may affect the distribution of outbreaks by *Operophtera* spp. and *Argyresthia retinella* (Lep., Yponomeutidae) (Tenow 1996; Tenow et al. 1999).

Higher summer temperatures would probably allow an increase in generalist enemies of insects and thus the area where the population dynamics of geometrid moths is more stable could extend northwards (cf. Neuvonen et al. 1999; Tanhuanpää 2000; Klemola et al. 2002). The combined effects of increased summer and winter temperatures on defoliation risks are extremely difficult to assess and different authors emphasise different aspects (Neuvonen et al. 1999; Niemelä et al. 2001). The defoliation risk is not the only thing we have to consider, the intensity and duration of outbreaks as well as the capacity of trees to recover from damage are also important (see Chap. 12).

There is some evidence that wintertime browsing could increase the quality of leaves for insects during the following summer (Danell and Huss-Danell 1985). Thus, it is in theory possible that higher moose densities (controlled partly by hunting regulations) might contribute to an increase in some herbivorous insects on birch. However, field tests in northern Sweden did not find a significant correlation between (simulated) browsing intensity and any of the indices of *E. autumnata* performance (Neuvonen and Danell 1987). Obviously, other impacts of ungulates are more important in the mountain birch forests (cf. Chaps. 10, 11).

One of the main factors hampering the regeneration of birch from seeds is reindeer grazing; results from field experiments show statistically significantly higher numbers of birch seedlings inside enclosures (protected) compared to outside enclosures (grazed; Lehtonen and Heikkinen 1995; see also Chap. 11). The mountain birch forests, especially in northernmost Finland, have a very low productivity (Chap. 4) and the regeneration of birch forests even in the absence of grazing would take decades (Chap. 12). Consequently, any attempts to reduce grazing pressure and restore the mountain birch forest ecosystems earlier damaged by insect outbreaks should be encouraged and supported.

Acknowledgements. Comments by and/or discussions with Arild Gautestad, Tero Klemola, Kai Ruohomäki, Olle Tenow and Frans Wielgolaski are gratefully acknowledged. Part of the study was supported by the EU through the HIBECO project (QLRT-CT99–1515).

References

Andersson G, Jonasson JÅ (1980) Relative abundance of insects on mountain birch at Ammarnäs, Swedish Lapland (in Swedish with English summary). Entomol Tidskr 101:61–69

Buck N, Callaghan TV (1999) The direct and indirect effects of enhanced UV-B on the moth caterpillar *Epirrita autumnata*. Ecol Bull 47:68–76

Bylund H (1995) Long-term interactions between the autumnal moth and mountain birch: the roles of resources, competitors, natural enemies and weather. PhD Diss, Swedish Univ Agr Sci, Uppsala

Bylund H (1997) Stand age-structure in a low population peak of *Epirrita autumnata* in a mountain birch forest. Ecography 20:319–326

Danell K, Huss-Danell K (1985) Feeding by insects and hares on birches earlier affected by moose browsing. Oikos 44:75–81

Hågvar S (1972) Altitudinal zonation of geometrid larvae (Lep.) during a mass occurrence on birch at Sogndal, western Norway, 1967. Entomol Scand 3:69–74

Harding R, Kuhry P, Christensen TR, Sykes MT, Dankers R, van der Linden S (2002) Climate feedbacks at the tundra-taiga interface. Ambio Spec Rep 12, Tundra-Taiga Treeline Res, pp 47–55

Haukioja E (1980) On the role of plant defenses in the fluctuation of herbivore populations. Oikos 35:202–213

Haukioja E, Neuvonen S, Hanhimäki S, Niemelä P (1988) The autumnal moth in Fennoscandia. In: Berryman AA (ed) Dynamics of forest insect populations. Patterns, causes, and implications. Plenum Press, New York, pp 163–178

Hogstad O (1997) Population fluctuations of *Epirrita autumnata* Bkh. and *Operophtera brumata* (L.) (Lep., Geometridae) during 25 years and habitat distribution of their larvae during a mass outbreak in a subalpine birch forest in central Norway. Fauna Norv Ser B 44:1–10

Johansen B, Karlsen SR, Tømmervik H (1995) Vegetasjonkartlegging og beitevurdering i norsk-svenske konvensjonområder. NORUT Rapport IT261/2–95:1–62

Kaitaniemi P, Neuvonen S, Nyyssönen T (1999) Effects of cumulative defoliations on growth, reproduction, and insect resistance in mountain birch. Ecology 80:524–532

Kallio P, Lehtonen J (1973) Birch forest damage caused by *Oporinia autumnata* (Bkh.) (Lep., Geometridae) in 1965–66 in Utsjoki, N Finland. Rep Kevo Subarctic Res Stn 10:55–69

Kallio P, Lehtonen J (1975) On the ecocatastrophe of birch forests caused by *Oporinia autumnata* (Bkh.) and the problem of reforestation. In: Wielgolaski FE (ed) Fennoscandian Tundra ecosystems, part 2. Animals and systems analysis. Ecological studies 17. Springer, Berlin Heidelberg New York, pp 174–180

Karhu KJ, Neuvonen S (1998) Wood ants and a geometrid defoliator of birch: predation outweighs beneficial effects through the host plant. Oecologia 113:509–516

Karlsson PS, Bylund H, Neuvonen S, Heino S, Tjus M (2003) Climatic response of budburst in the mountain birch at two areas in northern Fennoscandia and possible responses to global change. Ecography 26:617–625

Klemola T, Tanhuanpää M, Korpimäki E, Ruohomäki K (2002) Specialist and generalist natural enemies as an explanation for geographical gradients in population cycles of northern herbivores. Oikos 99:83–94

Kukkonen T (2002) Tunturikoivikon elpyminen tunturimittarin aiheuttamista tuhoista Kevon luonnonpuistossa. MSc Thesis, University of Turku, Department of Geography, 131 pp + 3 App

Laine K, Niemelä P (1980) The influence of ants on the survival of mountain birches during an *Oporinia autumnata* (Lep., Geometridae) outbreak. Oecologia 47:39–42

Lehtonen J, Heikkinen RK (1995) On the recovery of mountain birch after *Epirrita* damage in Finnish Lapland, with a particular emphasis on reindeer grazing. Ecoscience 2:349–356

Neuvonen S (1988) Interactions between geometrid and microtine cycles in northern Fennoscandia. Oikos 51:393–397

Neuvonen S, Danell K (1987) Does browsing modify the quality of birch foliage for *Epirrita autumnata* larvae? Oikos 49:156–160

Neuvonen S, Haukioja E (1991) The effects of inducible resistance in host foliage on birch-feeding herbivores. In: Tallamy DW, Raupp MJ (eds) Phytochemical induction by herbivores. Wiley, New York, pp 277–291

Neuvonen S, Niemelä P, Virtanen T (1999) Climatic change and insect outbreaks in boreal forests: the role of winter temperatures. Ecol Bull 47:63–67

Neuvonen S, Ruohomäki K, Bylund H, Kaitaniemi P (2001) Insect herbivores and herbivory effects on mountain birch dynamics. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and biosphere series 27. UNESCO, Paris and Parthenon, Carnforth, pp 207–222

Niemelä P (1980) Dependence of *Oporinia autumnata* (Lep., Geometridae) outbreaks on summer temperature. Rep Kevo Subarctic Res Stn 16:27–30

Niemelä P, Chapin FS III, Danell K, Bryant JP (2001) Herbivory-mediated responses of selected boreal forests to climatic change. Climatic Change 48:427–440

Nilssen A, Tenow O (1990) Diapause, embryo growth and supercooling capacity of *Epirrita autumnata* eggs from northern Fennoscandia. Entomol Exp Appl 57:39–55

Nuorteva P (1963) The influence of *Oporinia autumnata* (Bkh.) (Lep., Geometridae) on the timber-line in subarctic conditions. Ann Entomol Fenn 29:270–277

Nuorteva P (1966) Leaf development and leaf pathogens on subarctic birches after a calamity of *Oporinia autumnata* (Bkh.) (Lep., Geometridae). Ann Zool Fenn 3:270–286

Radeloff VC, Mladenoff DJ, Boyce MS (1999) Detecting Jack Pine Budworm defoliation by using spectral mixture analysis: separating effects from determinants. Remote Sensing Environ 69:156–169

Ruohomäki K (1994) Larval parasitism in outbreaking and non-outbreaking populations of *Epirrita autumnata* (Lepidoptera, Geometridae). Entomol Fenn 5:27–34

Ruohomäki K, Virtanen T, Kaitaniemi P, Tammaru T (1997) Old mountain birches at high altitudes are prone to outbreaks of *Epirrita autumnata* (Lepidoptera: Geometridae). Environ Entomol 26:1096–1104

Saelthun NR, Barkved LJ (2003) Climate change scenarios for the SCANNET region. Norw Inst Water Res (NIVA) Rep SNO 4663–2003, 74 pp

Saikkonen K, Neuvonen S (1993) European pine sawfly and microbial interactions mediated by the host plant. In: Wagner MR, Raffa KF (eds) Sawfly lifehistory adaptations to woody plants. Academic Press, San Diego, pp 431–450

Seppälä M, Rastas J (1980) Vegetation map of northernmost Finland with special reference to subarctic forest limits and natural hazards. Fennia 158:41–61

Sihvo J (2002) Ylä-Lapin luonnonhoitoalueen ja Urho Kekkosen kansallispuiston luontokartoitus. Loppuraportti osa 2: Ylä-Lapin luontotyypit. Metsähallituksen luonnonsuojelujulkaisuja Sarja A 137:1–170 + 3 maps (in Finnish with abstract in Swedish: Kartläggning av naturen i Övre Lapplands naturvårdsområde och Urho Kekkonens nationalpark. Slutrapport del 2: Naturtyper I Övre Lappland)

Suomela J, Neuvonen S (1997) Effects of long-term simulated acid rain on suitability of mountain birch for *Epirrita autumnata* (Geometridae). Can J For Res 27:248–256

Tanhuanpää M (2000) The role of natural enemies in preventing outbreaks of *Epirrita autumnata* in southern Finland. PhD Thesis, Univ Turku, Finland

Tanhuanpää M, Ruohomäki K, Kaitaniemi P, Klemola T (1999) Different impact of pupal predation on populations of *Epirrita autumnata* (Lepidoptera: Geometridae) within and outside the outbreak range. J Anim Ecol 68:562–570

Tanhuanpää M, Ruohomäki K, Uusipaikka E (2001) High larval predation rate in nonoutbreaking population of a geometrid moth. Ecology 82:281–289

Tanhuanpää M, Ruohomäki K, Turchin P, Ayres MP, Bylund H, Kaitaniemi P, Tammaru T, Haukioja E (2002) Population cycles of the autumnal moth in Fennoscandia. In: Berryman AA (ed) Population cycles: the case for trophic interactions. Oxford Univ Press, Oxford, pp 142–154

Tenow O (1972) The outbreaks of *Oporinia autumnata* Bkh. and *Operophthera* spp. (Lep., Geometridae) in the Scandinavian mountain chain and northern Finland 1862–1968. Zool Bidr Uppsala Suppl 2:1–107

Tenow O (1975) Topographical dependence of an outbreak of *Oporinia autumnata* Bkh. (Lep., Geometridae) in a mountain birch forest in northern Sweden. Zoon 3:85–110

Tenow O (1996) Hazards to a mountain birch forest – Abisko in perspective. Ecol Bull 45:104–114

Tenow O, Bylund H (1989) A survey of winter cold in the mountain birch/*Epirrita autumnata* system. Mem Soc Fauna Flora Fenn 65:67–72

Tenow O, Nilssen A (1990) Egg cold hardiness and topoclimatic limitations to outbreaks of *Epirrita autumnata* in northern Fennoscandia. J Appl Ecol 27:723–734

Tenow O, Nilssen AC, Holmgren B, Elverum F (1999) An insect (*Argyresthia retinella*, Lep., Yponomeutidae) outbreak in northern birch forests, released by climatic changes? J Appl Ecol 36:111–122

Tenow O, Bylund H, Holmgren B (2001) Impact on mountain birch forests in the past and the future of outbreaks of two geometrid insects. In: Wielgolaski FE (ed) Nordic mountain birch forest ecosystems. Man and biosphere series 27. UNESCO, Paris and Parthenon, Carnforth, pp 223–239

Tømmervik H, Høgda KA, Karlsen SR (2001) Using remote sensing for detection of caterpillar outbreaks in mountain birch forests, a new interesting approach. In: Wielgalski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp. 185–194

Tuhkanen S (1984) A circumboreal system of climatic-phytogeographical regions. Acta Bot Fennia 127:1–50 + 2 App

Virtanen T, Neuvonen S (1999) Performance of moth larvae on birch in relation to altitude, climate, host quality and parasitoids. Oecologia 120:92–101

Virtanen T, Neuvonen S, Nikula A (1998) Modelling topoclimatic patterns of egg mortality of *Epirrita autumnata* (Lep., Geometridae) with Geographical Information System: predictions for current climate and warmer climate scenarios. J Appl Ecol 35: 311–322

10 Birch Sapling Responses to Severity and Timing of Domestic Herbivore Browsing – Implications for Management

A.J. Hester, K. Lempa, S. Neuvonen, K. Høegh, J. Feilberg,
S. Arnthórsdóttir and G. Iason

10.1 Introduction

Grazing by wild and domestic herbivores has impacts on the growth and development of forests throughout Europe and many other parts of the world (Davis and Barrett 1992; Kuiters et al. 1996; Humphrey et al. 1998; Suominen and Olofsson 2001; Chaps. 4, 9, 11, 12, 17). Trampling and grazing activities can promote tree regeneration through the creation of gaps (Mitchell and Kirby 1991; Hester et al. 2000a), but heavy browsing and trampling of young trees can severely suppress their growth or in some cases lead to their death (Gill 1992a, b; Hester et al. 1996b; Chaps. 4 and 15). Thus, herbivores can have both positive and negative effects on forest development. Large herbivores are naturally part of both open and closed forest ecosystems, but the huge impacts of humans and their domesticated animals over many thousands of years have resulted in major losses of forest in many countries (Humphrey et al. 1998). Large mammalian herbivore numbers have generally increased over many hundreds of years, particularly domestic herbivores (although they are now decreasing in some countries; Hester et al. 2000a), but there have also been increases in numbers of some wild herbivores, encouraged for hunting by methods such as supplementary feeding (Humphrey et al. 1998). Thus, it is hard to find areas considered as having a 'natural' or 'sustainable' balance between forests and herbivores, although such terms are notoriously difficult to define! This perceived imbalance has resulted in a widespread need for a greater understanding of the interactions between forests and herbivores, to allow the design of 'sustainable' management practices for a range of different aims (Humphrey et al. 1998; Hester et al. 2000a).

Downy birch (*Betula pubescens*) is one of the most widespread native tree species across northern Europe and, being a pioneer species, regeneration mostly occurs on open or only partially wooded ground (Atkinson 1992).

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

Many such areas are often unfenced and are, therefore, fully open to grazing; hence, they are often extensively used by both wild and domestic herbivores. Indeed, in many northern countries, areas with birch (or other tree species) are often selected preferentially by herbivores (and by some farmers) because they provide shelter from more severe weather (Staines 1976; Hester et al. 2000a). The grazing and browsing activities of these herbivores have, in turn, direct impacts on the growth and regeneration dynamics of the birch forests within their range. Birch is generally classed as intermediate in relative preference by browsing herbivores (Gill 1992a) and appears to be relatively tolerant of repeated browsing (Kinnaird 1974; Miller et al. 1982; Gill 1992b). It exhibits flexible (neoformed) growth and has shown a greater capacity for compensatory growth following herbivore damage than other species such as pine (Danell et al. 1991, 1997; Hester et al. 2004; Chaps. 1, 5, 9).

The interactions between birch and domestic grazers, primarily sheep, are examined and discussed in this chapter, with particular focus on the sustainable management of both the forests and the livestock. This is an issue common to most northern European countries within the natural range of mountain birch. Case-study examples are drawn here from four countries: Scotland, northern Finland, Greenland and Iceland. Domestic sheep are free-grazed within areas of birch and open ground in all these countries. They are particularly numerous in Scotland, Greenland and Iceland, but are also still locally common in parts of northern Fennoscandia. Much of Finland's birch-dominated areas are also grazed by domestic reindeer (Helle 2001), which are thought to have similar effects on the growth and regeneration of these forests. Although this chapter focuses primarily on sheep, as reindeer are covered in Chapter 11, many issues are common to the impacts and management of both herbivores and so links are made throughout, as appropriate.

Although modern domestic sheep are primarily grazers or intermediate feeders with a propensity to graze on graminoid-dominated forage, almost all upland or hardy breeds also readily ingest species such as birch, as part of their diet (Hoffman 1989; Hester et al. 1996a, b). Much anecdotal and scientific evidence indicates that domestic sheep (and reindeer) can fundamentally affect the growth and regeneration of birch over wide areas (Lehtonen 1987; Fredskild and Ødum 1990; Lehtonen and Heikkinen 1995; Oksanen et al. 1995; Hester et al. 1996b; Mitchell et al. 1996; Aradóttir and Arnalds 2001; Helle 2001). However, we are still far from understanding, and therefore being able to predict, the main processes driving herbivore selection and birch responses under different conditions.

The main aims of this work, within the HIBECO project as a whole, were to quantify the effects of different levels of domestic herbivore damage at different times of the year and, from this, to explore common themes, management implications and recommendations for sustainable herbivore use of birch forest areas, within the context of the different land uses and requirements of each country. This chapter presents a summary of the findings from field observations and simulated browsing experiments under different environmental conditions, and an exploration of how changes in the current management regimes might affect the dynamics of these birch systems.

10.2 Case Studies and Experimental Designs

Examination of browsing impacts can be carried out by field monitoring of actual impacts and/or browsing simulation experiments. Field monitoring picks up real changes in areas where the selected herbivore is grazing, but it requires all other herbivores with similar browsing signs to be absent. Complementary manipulative experiments where browsing is simulated can give complete control over timing and severity of damage in a factorial, replicated design, thus allowing detailed comparative examination of factors driving the responses of birch saplings under more controlled conditions.

We therefore selected a combined approach with both field measurements and simulated browsing experiments, to measure the effects of timing and severity of browsing, with each experiment designed according to the conditions and resources within each country. In south Greenland the direct effects of sheep were recorded, as sheep were the only large herbivores in that area. In upland Scotland, red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) also use the same range as free-ranging sheep and their browsing 'imprints' on birch are very similar. In northern Finland, reindeer are the main ungulate herbivores using the same range as sheep and moose are also locally common; both would confound the quantification of sheep browsing impacts using field monitoring alone. Therefore, simulated browsing experiments were set up in Scotland and Finland, as it was beyond the resources of this project to fund large exclosure experiments with all herbivores other than sheep removed. Simulated browsing experiments were also set up in Iceland. Details of the grazing regimes and the status of birch in each country are given in the enclosed CD, together with details of study sites and experimental methods used.

10.3 Birch Responses to Timing and Severity of Browsing Damage

The results from the simulated browsing experiments in relation to birch responses from Finland, Scotland and Iceland (see experiment details in enclosed CD) are outlined below.

10.3.1 Severity of Browsing

Severity of simulated browsing by sheep had strong effects on all morphological parameters (particularly in Scotland with repeated treatments over 2 years), with reductions in sapling height, branching, shoot and leaf production with increased browsing severity after both 1 and 2 years of treatments. Many growth parameters in Finland and Iceland showed similar directional effects even after a single clipping, but most differences were not significant. Some other growth parameters (Scotland) only responded significantly to more severe clipping (66 %), i.e. basal stem diameter growth and sapling canopy area, indicating that thresholds of damage may be higher than for other growth responses.

Height growth is particularly important in terms of the time it takes for a sapling to grow out of reach of grazing animals, which for sheep would be about 1.5 m. To give an example of sapling height, Fig. 10.1 shows changes in sapling heights with treatment at the two Scottish sites (ANOVA: $p<0.01$). At one Scottish site (Corrimony), unclipped control saplings grew on average 6 cm/year, whereas growth of clipped saplings was at best 5 cm/year and at worst only 2 cm (see Sect. 10.3.2 below), which, even allowing for increases in height growth as sapling age, would result in the browsed saplings remaining within browse range for many more years. At the other Scottish site, even the control saplings only grew about 1.5 cm/year; the worst affected clipped

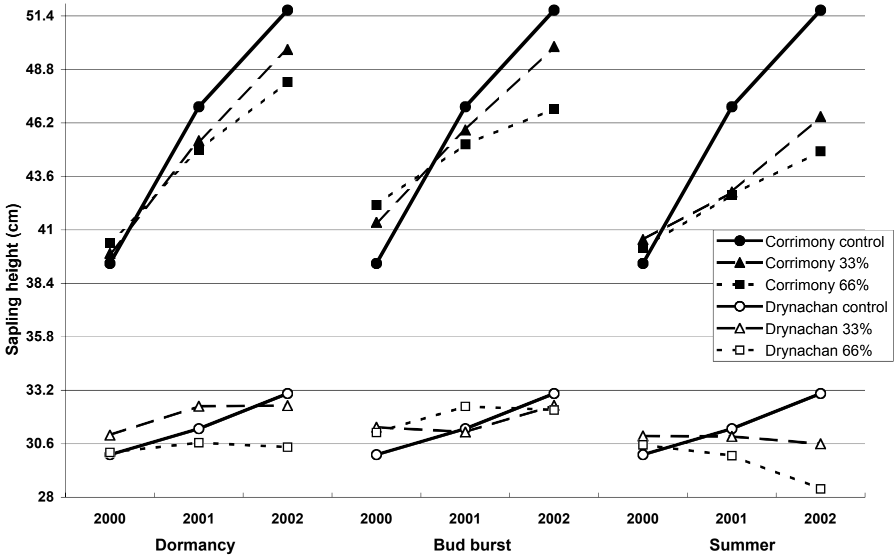


Fig. 10.1. Mean sapling height (cm) with simulated browsing treatment over 2 years at two Scottish sites. *Horizontal grid lines* represent one LSD at $p<0.05$ (Anova)

saplings actually showed reduced height growth over the 2 years. Mean height growth in Finland varied from a maximum of 16 cm to a negative height growth of a few centimetres (early summer heavy clip, Skallovaara), but height growth was extremely variable both within and between sites and no differences were statistically significant. Height growth in Iceland was minimal for all saplings, including ungrazed controls, and so they would be predicted to remain within browse range for many years.

Leaf, shoot and branch production all affect the degree of 'bushiness' of a sapling and have been shown to strongly influence herbivores in their choice of saplings to browse (Iason et al. 1996). Figure 10.2 gives an example from Scotland of treatment effects on numbers of leaves produced after 1 and 2 years of clipping (ANOVA: $p<0.001$). At both sites, the most severe clipping resulted in leaf production being reduced by almost 50 %. Branch production was similarly reduced. Such reductions have major effects on forage availability as well as sapling growth. Importantly, Fig. 10.2 also illustrates clearly the magnitude of year-by-year differences in some growth parameters, with 2001 having much better leaf growth than 2002 even for control saplings, indicating that this is not a treatment response, but presumably a response to climatic conditions. Interactions between herbivore impacts and year-by-year changes in climatic factors are clearly important for management, and sensitive manipulation of herbivore numbers in response to climatic variation might be essential in some of these northern areas, as is regularly carried out

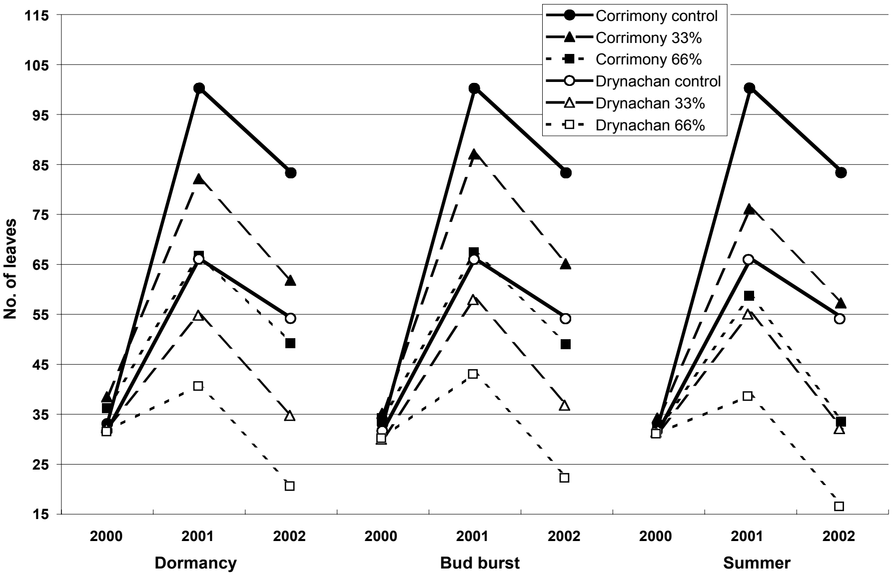


Fig. 10.2. Mean number of leaves per sapling with simulated browsing treatment over 2 years at two Scottish sites. *Horizontal grid lines* represent one LSD at $p<0.05$ (Anova)

in more semi-arid parts of the world in response to changes in water availability (e.g. Scogings 1998; Weber et al. 1998). The importance of following experimental treatments over as long periods as possible, in order to understand the affects of fluctuating climatic influences, cannot be overstated.

Relative growth rate of the meristem population strongly affects growth capacity in the year(s) following damage, and this was also significantly negatively affected by severity of clipping in both Scotland and Finland. At Syysjoenpalo (a poor, dry Finnish site), for example, the increase in bud numbers was significantly greater in the control compared to moderately clipped saplings, which in turn produced more new buds than heavily clipped saplings, as shown in Fig. 10.3 (ANOVA: $p<0.001$).

Compensatory growth was also apparent for some parameters, as is well established for birch (Hjältén et al. 1993; Danell et al. 1997). In Scotland, long shoots (and leading shoots) grew significantly longer as a compensatory response to clipping, even after two successive years of treatments (although timing of browsing also had major effects on this response; see below), and the proportions of long:short shoots also increased, as has also been found in other studies (Danell and Bergström 1989). Similar compensatory shoot growth was also found in Finland and Iceland, although the differences were

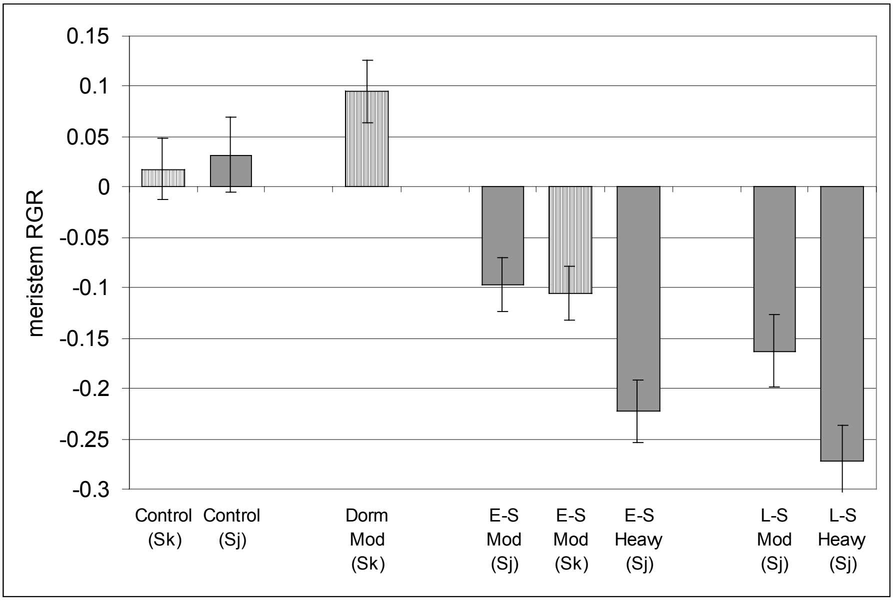


Fig. 10.3. Meristem RGR comparisons 2 years after simulated browsing at two Finnish sites – mean difference in total number of new growing points (buds) in autumn 2002 as compared to pre-treatment, 2000. *Sk* Skallovaara; *Sj* Syysjoenpalo; *Dorm* dormant clip; *E–S* early summer clip; *L–S* late summer clip

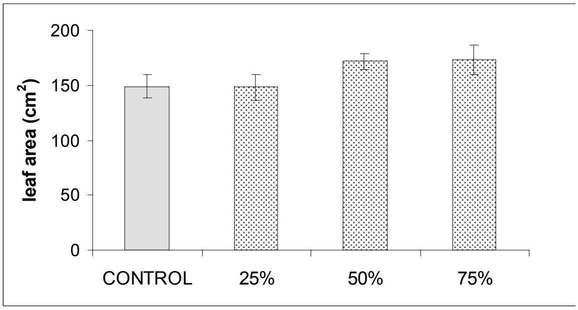


Fig. 10.4. Mean leaf areas of birches (August 2001), ±SE, clipped in June 2001, Þórðarstaðaskógur, Iceland

not significant. Leaf area measurements in Iceland also showed compensatory responses as expected, but only with the more severe clipping (Fig. 10.4). Continuation of the clipping treatments in Scotland will test how such compensatory growth responses change as the plant resources are repeatedly reduced by removal of plant material year after year.

10.3.2 Timing of Browsing

The timing of simulated browsing was also shown to be extremely important, with the strongest, detrimental effects in late summer compared to early summer or winter, and strongest compensatory effects in saplings clipped at dormancy, in both Finland and Scotland. In Scotland, most growth parameters were significantly reduced after late summer clipping, with treatment effects increasing over the 2 years (see examples in Figs. 10.1 and 10.2, all $p<0.001$). Simulated browsing at dormancy also resulted in the strongest meristem regrowth (RGR) in both Scotland and Finland. At Skallovaara (the richest and most elevated site in Finland), for example, after 2 years dormant-clipped saplings produced just as many new buds as controls, and significantly more than saplings clipped in early summer (Fig. 10.3; $p<0.02$).

10.3.3 Locational Effects

All main treatment effects were consistent across sites and countries, despite the differences in soils, local climate, surrounding vegetation height and browsing history, indicating consistency of measured responses to simulated browsing of birch, independent of local conditions. The stronger effects at the Scottish sites reflected the repeated application of the simulated browsing treatments over 2 years, as opposed to single simulated browsing treatments in both Finland and Iceland.

10.3.4 Implications for the Management of Herbivore Grazing Within Birch Areas of Northern Europe

Overall indications from the experiments in Finland and Scotland were that simulated browsing in winter was least detrimental to the regrowth of birch, spring/early summer effects were mostly intermediate, whilst late summer browsing had the most detrimental effects on sapling growth. As expected, increasing severity of simulated browsing also had increasingly detrimental effects on many growth parameters, particularly in late summer. Similar results have also been reported elsewhere (e.g. Danell and Bergström 1989; Senn and Haukioja 1994; Hester et al. 2004). However, with the exception of one site in Scotland (Drynachan, with 1 % death so far), no treatments had sufficiently severe effects on sapling growth to kill them within the relatively short time of this study. Even saplings subjected to the heaviest (Finland: 100 %) clipping recovered almost fully within 2 years of clipping, which indicates that recovery, at least from short spells of heavy browsing, will be fast. The results therefore indicate that light to moderate browsing on birch may be acceptable, particularly in winter, depending on the aims for any particular site (timber production being the most demanding, as growth form is crucial). However, it is possible that winter damage under severe conditions (e.g. Greenland) could increase desiccation damage or fungal/bacterial incursions – more years of data would be required to compare climatically different winters to ascertain how this might vary between severe and mild winters.

However, the results of these studies are short term and if browsing continues over more than a few years, it is likely that the effects will become increasingly apparent if the resources of the saplings are being repeatedly depleted (Danell and Bergström 1989; Millard et al. 2001). The gradual increase in height differences between control and clipped saplings (each year) shown in Fig. 10.1 (especially those clipped in late summer) also supports this assertion. The example below for Greenland (Fig. 10.4) provides a good illustration of longer-term damage from continued heavy grazing. Two years (the duration of these studies) is a short time in the life of a forest, so this work established under the HIBECO project provides an ideal baseline from which to continue simulated browsing of some saplings whilst leaving others to recover, in order to provide comparative data on both types of scenario. Longer term data (from the Scottish site where treatments are continuing) will give fuller information on how all these responses change as the saplings age, as well as how well they recover once simulated browsing has ceased.

It is also important to consider that different sapling responses to browsing may also increase or decrease their subsequent susceptibility to browsing (both physically and chemically; Hester et al. 2004), because other factors affecting sapling form, such as branching, density of long shoots and density of leaves have all been shown to influence herbivore choice (e.g. Iason et al. 1996). Herbivore diet preferences also differ seasonally as well as between areas with different combinations of forage available. These factors, and the trade-offs between rapid regrowth and susceptibility to further damage, have major management implications in systems where the aim is for herbivores and trees to coexist. Such issues continue to be widely discussed and are not yet resolved (Löyttyniemi 1985; Danell and Bergstrom 1989; Bryant et al. 1992; Iason et al. 1996; Danell et al. 1997; Hester et al. 2000a, 2004). For example, although the effects of browsing on birch appear to be more detrimental in late summer, there is no point imposing bans on late summer grazing if, for example, the animals prefer alternative forage at that time of year (e.g. grasses; Hofman 1989), and rarely choose birch. Research on factors affecting herbivore forage preferences needs to be carried out alongside the kind of research presented here on sapling responses in order to make meaningful conclusions about how best to manage timing as well as densities of herbivores for specific birch regeneration aims.

In addition to the effects of sheep discussed here, combinations of insect and large mammalian herbivores create a complex problem for the birch forest ecosystem over much of Fennoscandia (Lehtonen 1987; Lehtonen and Heikkinen 1995; Chap. 9). Furthermore, damage to the birch (and other vegetation) is not the only problem where sheep numbers are high. In Iceland, for example, where the birch forests represent one of the most productive vegetation types for sheep grazing (Thorsteinsson 1963), heavy grazing by sheep has also resulted in widespread erosion, which can be very difficult to redress (Aradóttir and Arnalds 2001). Erosion is a much more localised problem in Scotland, Greenland and Fennoscandia (see Chap. 4), but it nonetheless can be locally important. Birch woodlands growing at the extremes of their range, or in particularly unstable landscapes, are considered to be particularly vulnerable to damaging grazing levels and their recovery is much slower than further south, particularly where erosion also takes place, and/or insect outbreaks are common. Thus the consequences of inappropriate grazing management can have far more severe effects in some areas than in others.

10.4 Theory Versus Reality: Case-Study Example of Sheep Impacts in Greenland

Although most studies of birch have shown it to be relatively tolerant of browsing damage, many areas of birch with a long history of sheep grazing have shown major declines in numbers of trees, as well as severely suppressed regeneration under certain conditions. This is well illustrated by the case study in Greenland (Fig. 10.5), as well as many similarly degraded parts of Scotland (Hester 2001) and Iceland (Aradóttir and Arnalds 2001). Numbers of domestic sheep have normally been extremely high in such areas, resulting in very heavy browsing pressure (in some parts of Scotland sheep remove

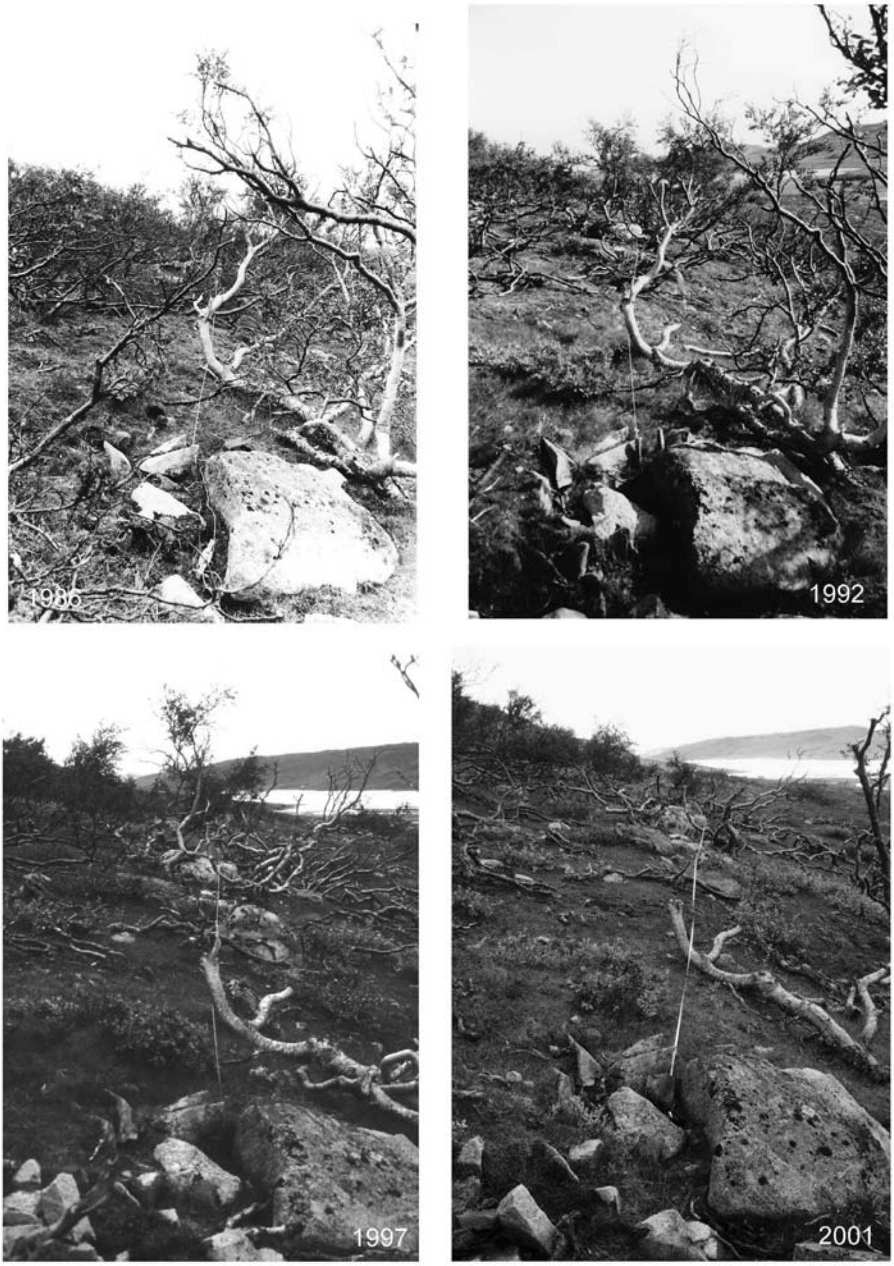


Fig. 10.5. Successive photos of one of the birches in the area of the study farm grazed year-round, Greenland. (Photos from 1986 to 2001, Jon Feilberg)

90–100 % of new shoots year after year), which is heavier than the simulated browsing levels shown to have relatively limited effects. Sheep browsing has also normally been sustained (either year-round or seasonally) over many (often hundreds of) years in these areas, in contrast to the experimental results presented earlier, i.e. for growth responses over 2 years or less. Long-term measurements of the effects of browsing on birch by known densities of sheep are relatively scarce and this lack of information needs to be addressed before meaningful management conclusions can be made and implemented (Hester et al. 1996b, 2004).

The farm selected for study in Greenland had year-round grazing by sheep close to the farm, and summer grazing in a wider area around the farm. The recommended maximum stocking rate is 2740 ewes with 1.4 lambs during 5 months of summer grazing (May–October; Thorsteinsson 1983); actual sheep numbers were approximately 2000 ewes over the whole grazing area (approx. 5.4 ha per ewe), and have been so for the last 10 years. However, because only about 30 % (or less) of the area was used by the sheep in winter (that closest to the farm), the sheep winter densities were probably more than three times higher in that small area of ground, compared to the extensive area grazed only in summer. Figure 10.6 shows the mean percentage of shoots browsed within each treatment area. Major differences were found in the severity of birch browsing between summer-grazed and year-round grazed areas: sample birches in areas grazed year-round had just under twice the amount of grazing damage as compared to those grazed only in summer (ANOVA: $p<0.001$; low grazing in the 'ungrazed' plot represented a combination of arctic hare

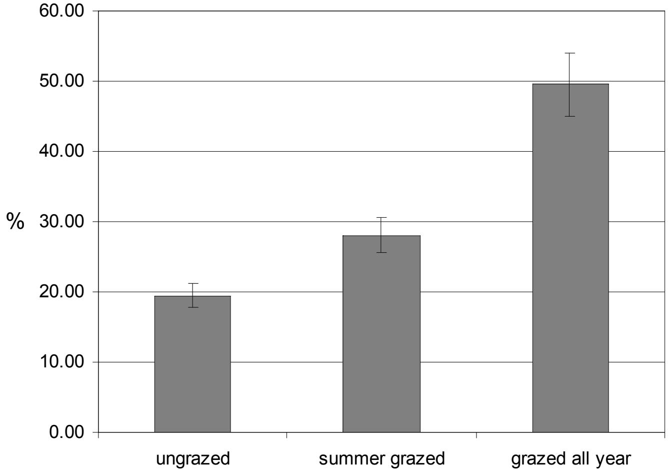


Fig. 10.6. Mean (±SE) percentage of shoots grazed by sheep on sample birch trees in Greenland. Treatment areas were either grazed only in summer, or grazed year-round, with an ungrazed control plot

and probably also occasional incursions by sheep). Examination of Fig. 10.5 indicates that year-round grazing by sheep was clearly much more damaging than summer grazing only overall, but it is important to note that when divided by the much heavier sheep use per area in winter, this actually indicated proportionally less shoot damage (i.e. shoots browsed per sheep grazing day per area) in winter as compared to summer. In the area grazed year-round, although only about half the shoots were browsed on average (Fig. 10.6); locally, these reached 80–90 % in the area shown in Fig. 10.5, with many dead or dying birches, whereas most birches in the summer-grazed area were in much better condition.

However, this does not take into account damage from rubbing and trampling (both almost certainly influencing the decline of birch in the photo sequence). Non-grazing effects have rarely been directly measured in birch or any other vegetation. There is a strong need for such research, especially in relation to woody species, whose stems are often particularly vulnerable to breaking, as such impacts are likely to be major drivers of change in woody vegetation cover in areas such as this (see Hester and Baillie 1998). Despite the results of simulated browsing studies indicating the most severe effects on birch regrowth in late summer, it is possible that combinations of browsing and trampling may actually have more severe effects in winter, particularly in more climatically extreme environments where the consequences of winter damage, in terms of dessication and disease incursion, are more severe.

10.4.1 Economics

Whatever the main causal factors, there is little doubt that year-round grazing by sheep in Greenland has the potential to locally devastate areas of birch, as indeed has been reported over much of Iceland in the past, when winter grazing was more prevalent (Hólmgeirsson 1977/1978; Aradóttir and Arnalds 2001). Many other areas in Greenland show large differences in damage to birch between areas which are only summer-grazed and areas grazed year-round, and there is now increasing pressure on farmers to stop grazing sheep in the birch forests in winter in view of the heavy destruction to this species (Fig. 10.5). However, if sheep are removed from these areas in winter they need alternatives, the most common of which is to house them indoors in winter. This requires a building and extra food, so the economics need to be carefully considered. Data have been collected from various farms to try to assess the effect of the different grazing regimes on sheep welfare and production, as well as plant production. Figure 10A in the CD accompanying this volume shows changes in mean sheep carcass weights between 1980 and 2001 from farms in two grazing areas in the Qassiarsuk region of Greenland. The area grazed year-round (area 1, where the HIBECO plot is situated) is compared with the neighbouring grazing area, which has not been grazed in winter since 1994. Sheep carcass weights increased by about 8 % over 8 years in the area where winter grazing was stopped, compared to the farms still grazed year-round (paired *t*-test 1995–2001: $p<0.001$), with visually better birch production in the area with no winter grazing. The combination of research on herbivore impacts together with the economic implications is crucial in order to translate the research results into practicable and affordable management options.

10.5 Current Activities to Improve Grazing Management in Birch Forest Areas

In Scotland, many changes in approaches to native species such as birch have been taking place over the last 10–20 years, with the provision of government agency grant aid for fencing to exclude large herbivores and protect areas for natural regeneration, new planting of native trees, and management agreements to reduce numbers of both sheep (often promoted by targeted incentives for farmers) and deer (by shooting) in certain areas. Native forest cover, including birch, is now starting to significantly increase. For example, in the last 5 years, new native forest has been established over 0.5 % of Scotland's land area, through government grant aid. In Iceland, widespread reintroduction of birch into areas where it had disappeared has also been accomplished by both direct seeding and planting of seedlings (Aradóttir and Arnalds 2001).

However, it is important to highlight the fact that the prime method used to encourage woodland regeneration in all four countries discussed here is still the exclusion of large herbivores by fencing, rather than by targeted management of sheep densities or timing of grazing. There is no doubt that total exclusion of herbivores can be a quick solution, particularly in areas where it is difficult to regulate numbers by any other means. Nevertheless, for many reasons, it is not generally considered to be the best medium- to long-term solution. It has been widely shown that germination of birch is better in areas where grazing animals are present than in areas fenced to exclude them (Miles and Kinnaird 1979; Hester et al. 1996b, 2000b).

Herbivore exclusion also removes the possibility of using the woods for shelter (very important for the animals in exposed areas), fencing is not economically viable in many areas, and it has major effects on landscape features as well as forest structure, diversity and regeneration, particularly in the medium to longer term (Mitchell and Kirby 1991; Hester and Miller 1995; Gilbert et al. 1997). The alternative to exclusion, therefore, is to manage herbivore numbers and timing of grazing, but grazing management guidance is still inadequate for birch forest systems, because, as discussed earlier, so few scientific studies have been conducted to elucidate such information, particularly for sheep (Hester et al. 1996b, 2000a; Gilbert et al. 1997).

In northern Fennoscandia, although reindeer are much more of a problem for birch regeneration than sheep due to their much greater densities (see Chaps. 4 and 11), the actions being taken to address this issue are highly relevant for sheep as well. In a unique project (cf. Chaps. 11 and 19), a local municipality, the Finnish Forest and Park Service, and local reindeer herders have taken the joint initiative to reduce reindeer grazing pressures during early summer (when birch seedlings are preferred forage) in two large experimental areas. Birch regeneration will also be enhanced in smaller areas by planting seedlings and/or sowing seeds to form birch forest islands as new dispersal centres in the deforested areas. Birch forest recovery under these harsh conditions will require decades, however, as it is currently so depleted. In Scotland, several large areas of land bought in recent years by conservation organisations have also initiated major management interventions to reduce herbivore numbers and allow successful tree regeneration, by removing domestic sheep and culling red and roe deer (e.g. Beaumont et al. 1994). However, such initiatives have, to date, been very limited in extent and, as in Finland, recovery can be locally slow due to harsh conditions and lack of seed sources in heavily de-forested areas.

Government policy in Iceland since the mid–late 20th century has acted to increasingly control grazing on common land (to reduce erosion of vegetation and soil); grazing control of cultivated land is already quite well established (Thorsteinsson 1963; Arnalds 1988; Aradóttir and Arnalds 2001; Icelandic Ministry for the Environment 2001). For example, one suggested way to maintain Iceland's woodlands was to fully protect them for a period of time twice every century (Skúlason 1996), mostly to protect regenerating birch. It is hoped that through more research, specific grazing loads (rather than removal) may be identified which still allow sufficient birch regeneration.

In addition, in Iceland, removal of winter grazing has already happened in most places due to its damaging effects, through direct government regulations; in Greenland this is still a highly controversial issue. The limited evidence so far in Greenland indicates that winter damage to birch areas is severe and difficult to reverse, partly because of the intense pressure on relatively small areas of land close to the farms. Whether or not complete cessation of grazing is required, or whether major reductions in sheep numbers using the land in winter would also achieve the desired aims of protecting the birch, is not known.

10.6 Conclusions

It is clear that there is potential to manipulate domestic herbivore numbers more sensitively to manage both herbivores and forests together, but this is still not being done in many parts of Europe, partly because awareness takes time to filter through a population, incentives are often required, but not necessarily delivered by the government, and also because the answers to all the required questions are not yet known. The work summarised in this chapter has strengthened some existing findings and highlighted other new ones. There is still a strong need for intensive, targeted research specifically designed to fully address this complex issue and produce the information required to support management decisions on how best to integrate herbivores with the active pursuit of natural forest regeneration. These issues are common in many European countries, especially those with very little native forest cover (e.g. Denmark, Iceland, Greenland, UK), but also in several countries where native forest cover is still high (e.g. Finland, Germany, Norway, Sweden; Humphrey et al. 1998).

Acknowledgements. Grateful thanks are extended to Gordon Baillie, David Sim and Tracy Brown, for help with the fieldwork, sorting, measuring and weighing of birch samples in the lab (Scotland data). We are also grateful to David Elston of BioSS for statistical advice (Scotland data); Lauri Kapari, Esko Tainio and Jari Ovaska for fieldwork help in Finland; Poul Bjerge (Qaqortoq) for providing housing for Jon Feilberg during the fieldwork in Qanasiassat (Greenland); Sesselja G. Sigurðardóttir, María B. Arnardóttir, Patrick Wingfield Digby, Anna Bragadóttir, Elin Larsson, and Guðni Þ. Þrándarson for helping with the fieldwork, sample measurements and data input in Iceland.

References

Aradóttir Á, Arnalds Ó (2001) Ecosystem degradation and restoration of birch woodlands in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York,pp 293–306

Arnalds A (1988) Vegetation conservation (in Icelandic). Græðum Ísland 1:209–220

Atkinson MD (1992) Biological Flora of the British Isles: *Betula pendula* Roth (*B. verrucosa* Ehrh.) and *B. pubescens* Ehrh. J Ecol 80:837–870

Beaumont D, Dugan D, Evans G, Taylor S (1994) Deer management and tree regeneration in the RSPB reserve at Abernethy forest. In: Aldous CP (ed) Our pinewood heritage. Forestry Commission, Edinburgh, pp 186–195

Bryant JP, Reichardt PB, Clausen TP (1992) Chemically mediated interactions between woody plants and browsing mammals. J Range Manage 45:18–24

Danell K, Bergström R (1989) Winter browsing by moose on two birch species: impact on food resources. Oikos 54:11–18

Danell K, Niemelä P, Varvikko T, Vuorisalo T (1991) Moose browsing on Scots pine along a gradient of plant productivity. Ecology 72:1624–1633

Danell K, Haukioja E, Huss-Danell K (1997) Morphological and chemical responses of mountain birch leaves and shoots to winter browsing along a gradient of plant productivity. Ecoscience 4:296–303

Davis LS, Barrett RH (1992) Spatial integration of wildlife habitat analysis with long-term forest planning over multiple-owner landscapes. In: Le Master DC, Sedjo RA, Balestreri SA (eds) Modelling sustainable forest ecosystems. Washington State University Press, Pullman, Washington, pp 143–154

Fredskild B, Ødum S (1990) The Greenland mountain birch zone, an introduction. The Greenland mountain birch zone, southwest Greenland. Meddr Grønland, Bioscience 33:3–7

Gilbert D, Horsefield D, Thompson DBA (1997) The ecology and restoration of montane and subalpine scrub habitats in Scotland. Scottish natural heritage review 83. Scottish Natural Heritage, Battleby

Gill RMA (1992a) A review of damage by mammals on north temperate forests: 1. Deer. Forestry 65:145–169

Gill RMA (1992b) A review of damage by mammals on north temperate forests: 3. Impact on trees and forests. Forestry 65:363–388

Helle T (2001) Mountain birch forests and reindeer husbandry. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 279–291

Hester AJ (2001) Grazing management and forest regeneration in marginal areas. Ann Icelandic For Soc (Skograektarritid) 1:97–103

Hester AJ, Baillie GJ (1998) Spatial and temporal patterns of heather use by sheep and red deer within natural heather/grass mosaics. J Appl Ecol 35:772–784

Hester AJ, Miller GR (1995) Scrub and woodland regeneration: prospects for the future. In: Thompson DBA, Hester AJ, Usher MB (eds) Heaths and moorlands: Cultural landscapes. HMSO, Edinburgh, pp 140–153

Hester AJ, Miller DR, Towers W (1996a) Landscape scale vegetation change in the Cairngorms, Scotland, 1946–1988: implications for land management. Biol Conserv 7:41–52

Hester AJ, Mitchell FJG, Kirby KJ (1996b) Effects of season and intensity of sheep grazing on tree regeneration in a British upland woodland. For Ecol Manage 88:99–106

Hester AJ, Edenius L, Buttenshøn RM, Kuiters AT (2000a) Interactions between forests and herbivores: the role of controlled grazing experiments. Forestry 73:381–391

Hester AJ, Stewart FE, Racey PA, Swaine MD (2000b) Can gap creation by red deer enhance the establishment of birch (*Betula pubescens*)? Scott For 54:143–151

Hester AJ, Millard P, Baillie GJ, Wendler R (2004) How does timing of browsing affect above- and below-ground growth of *Betula pendula*, *Pinus sylvestris* and *Sorbus aucuparia*? Oikos 105:536–550

Hjältén J, Danell K, Ericson L (1993) Effects of simulated herbivory and intraspecific competition on the compensatory ability of birches. Ecology 74:1136–1142

Hofmann RR (1989) Evolutionary steps of ecophysiological adaptation and diversification of ruminants; a comparative view of their digestive system. Oecologia 78:443–457

Hólmgeirsson G (1977/1978) Horse browsing and the deterioration of Icelandic forests (in Icelandic). Ann Iceland For Assoc 11

Humphrey J, Gill R, Claridge C (1998) (eds) Grazing as a management tool in European forest ecosystems. Forestry Commission Technical Paper 25. Forestry Commission, Edinburgh

Iason GR, Duncan AJ, Hartley SE, Staines BW (1996) Feeding behaviour of red deer (*Cervus elaphus*) on Sitka spruce (*Picea sitchensis*): the role of carbon:nutrient balance. For Ecol Manage 88:121–129

Icelandic Ministry for the Environment (2001) Sustainable development in the Icelandic society – action plan for the turn of the century (in Icelandic). http://brunnur.stjr.is/, pp 1–23

Kinnaird JW (1974) Effect of site conditions on the regeneration of birch (*Betula pendula* and *pubescens* Ehrh.). J Ecol 62:467–472

Kuiters AT, Mohren GMJ, van Wieren SE (1996) (eds) Ungulates in temperate forest ecosystems. Elsevier, Amsterdam

Lehtonen J (1987) Recovery and development of birch forests damaged by *Epirrita autumnata* in Utsjoki area, North Finland. Rep Kevo Subarct Res Stn 20:35–39

Lehtonen J, Heikkinen RK (1995) On the recovery of mountain birch after *Epirrita* damage in Finnish Lapland, with a particular emphasis on reindeer grazing. Ecoscience 2:349–356

Löyttyniemi K (1985) On repeated browsing of Scots pine saplings by moose. Silv Fenn 19:387–391

Miles J, Kinnaird JW (1979) Grazing, with particular reference to birch, juniper and Scots pine in the Scottish Highlands. Scot For 33:280–289

Millard P, Hester AJ, Wendler R, Baillie G (2001) Remobilization of nitrogen and the recovery of *Betula pendula, Pinus sylvestris,* and *Sorbus aucuparia* saplings after simulated browsing damage. Funct Ecol 15:535–543

Miller GR, Kinnaird JW, Cummins RP (1982) Liability of saplings to browsing on a red deer range in the Scottish Highlands. J Appl Ecol 19:941–951

Mitchell FJG, Kirby KJ (1991) The impact of large herbivores on the conservation of semi-natural woods in the British uplands. Forestry 63:333–353

Mitchell FJG, Hester AJ, Kirby KJ (1996) Effects of season and intensity of sheep grazing on a British upland woodland: browsing damage to planted saplings. Bot J Scotl 48:199–207

Oksanen L, Moen J, Helle T (1995) Timberline patterns in northernmost Fennoscandia. Relative importance of climate and grazing. Acta Bot Fenn 153:93–105

Scogings PF (1998) Resistance of six savanna woody plant species to browsing by goats in the Eastern Cape Province of South Africa. PhD Thesis, Univ Fort Hare, Alice

Senn J, Haukioja E (1994) Reactions of the mountain birch to bud removal: effects of severity and timing, and implications for herbivores. Funct Ecol 8:494–501

Skúlason B (1996) The co-habitation of forestry and sheep farming (in Icelandic). Freyr 6:31–32

Staines BW (1976) The use of natural shelter by red deer in north-east Scotland. J Zool 180:1–8

Suominen O, Olofsson J (2001) Impacts of semi-domesticated reindeer on structure of tundra and forest communities in Fennoscandia: a review. Ann Zool Fenn 37:233–249

Thorsteinsson I (1963) Research on the effects of grazing on the vegetation of Landmannaafréttur (in Icelandic). Náttúrufræðingurinn 33:187–203

Thorsteinsson I (1983) Undersøgelser af de naturlige græsgange i Syd-Grønland 1977–1981. Landbr Forsk Inst, Island, Forsøgsstat Upernaviarsuk, Grønland, 223 pp

Weber GE, Jeltsch F, van Rooyen N, Milton SJ (1998) Simulated long term vegetation response to grazing heterogeneity in semi-arid rangelands. J Appl Ecol 35:687–699

11 Effects of Reindeer Grazing on Pastures – A Necessary Basis for Sustainable Reindeer Herding

K. Lempa, S. Neuvonen and H. Tømmervik

11.1 Introduction

Reindeer grazing reduces plant biomass and diversity. Only some lichen and grass species and mosses can take advantage of grazing disturbance (Suominen 1999; Virtanen 2000; Bråthen and Oksanen 2001; Helle 2001; Suominen and Olofsson 2001). Effects of overgrazing have been found in both wild (Manseau et al. 1996; Gaare 1997) and domesticated reindeer populations (Suominen and Olofsson 2001). The number of reindeer in northern Fennoscandia has undergone large spatial and temporal variation. Many recent studies indicate that pastures are overgrazed (Kumpula 2001; Stark 2002; Tømmervik et al. 2004; see also Chaps. 4 and 17). However, other pastures (e.g. Sweden and Eastern Finmark) are in good condition or only slightly damaged (Gaare and Tømmervik 2000, Moen and Danell 2003, Sandström et al. 2003). The variability in numbers of reindeer and pasture conditions results from variability in productivity and climatic conditions as well as different herding systems practised in different parts of northern Fennoscandia.

Mountain birch forest is an important part of reindeer pasture (Helle 2001). Access by Sámi to mountain birch forest and protection from deterioration of such forest are two necessary, but not sufficient conditions, for sustainable reindeer herding (Riseth 2000). It is essential for sustainable reindeer herding to understand the dynamics of reindeer numbers and their effects on the amount and availability of the most important fodder plants in pastures. Besides the ecological framework, the condition of the pastures is dependent on human activity. Reindeer herders, administrators and politicians have to a large extent regulated the modes and intensity of reindeer herding (see Chap. 19), which have modified both number of reindeer and condition of pastures.

To estimate the effects of reindeer herding on pastures, several controlled studies on reindeer browsing have been made. Analyses are carried out to

---

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

determine which pasture components are most vulnerable to reindeer grazing and how the response is dependent on the actual reindeer density. In Chapter 19 the reindeer herding practices and the long-term vegetation changes are described in the western part of the county of Finnmark, Norway, where traditional annual migrations and pasture rotations are commonly practised. Also described are some historical and economical changes over the last 150 years which have affected herding practices and thereby changed both the number of reindeer and their pasture quality in Finland, Sweden and Norway. Finally, based on the material presented, it is shown how the interplay between ecological, historical and economical factors affects sustainability of reindeer herding in the mountain birch ecosystem.

The condition of reindeer pastures is an outcome of natural processes, i.e. herbivore–plant interaction and climatic variation. In addition, the pasture condition is regulated by international agreements and administrative decisions. The choice of best practices is always constrained by the natural conditions in the herding community. The successful application of these practices is dependent on the cultural background and economic situation of the herding community (see Chap. 19).

11.2 Climatic Variability

The most important abiotic factor, climatic variability, modifies reindeer productivity (Post and Stenseth 1999; Putkonen and Roe 2003; Chaps. 1 and 4). However, climate change will have different effects on reindeer herding in different areas of Fennoscandia (Post and Stenseth 1999; Lee et al. 2000). One scenario predicts that strong North Atlantic oscillations and the associated relatively warm winters will bring about snow conditions that will reduce grazing efficiency in winter pastures (Lee et al. 2000; Putkonen and Roe 2003). On the other hand, higher precipitation will improve the productivity of inland areas in northern Fennoscandia. Scenarios of climate change should be included in the sustainable management plans (cf. Chaps. 19, 23, 24, 25). Microgeographical variation affects lichen availability in alpine heaths. The rugged habitats have the highest lichen availability, since rocks reduce formation of ice layers in the snow (Nellemann 1996; cf. Tømmervik et al. 2004; Chap. 17). Both biotic and abiotic conditions vary at all scales (local, regional and national). Therefore, there is not a single ecological solution to socially and economically sustainable management practices (cf. Chap. 19).

11.3 Trends and Patterns in Reindeer Population Densities in Northern Fennoscandia

The reindeer censuses conducted by reindeer authorities in Finland, Norway and Sweden indicate considerable density fluctuations in the last century and also variation between districts (cf. Chaps. 16 and 24). However, the most recent figures suggest that the shift from low densities to higher densities in the early 1980s was quite synchronised in all three countries (Fig. 11.1). In the Finnish mountain birch zone, in the Paistunturin co-operative herding district, the highest densities were over two-fold in respect to the lowest densities during the census period. Since 1835 the reindeer population in western Finnmark county in Norway has encountered strong density fluctuations. In the 1980s, densities were at their highest level. The highest number of reindeer (8.3 reindeer/km^2) in this period was over four-fold higher than the lowest number in the early 1950s (1.9 reindeer/km^2). In contrast, density fluctuations in Norrbotten county in Sweden have been relatively small, as the highest density (5 reindeer/km^2) in 1955 was only two-fold higher than the lowest density (2.3 reindeer/km^2) in 1974. A more detailed reindeer census in Norrbotten, Sweden, in 1930–1964 showed population densities ranging from 95,600 to 225,600 individuals, a more than two-fold difference between the highest and lowest year (Fig. 11.1).

At that time the reindeer populations were managed mostly by traditional methods. Motorised herding, anti-parasitic vaccination and supplementary

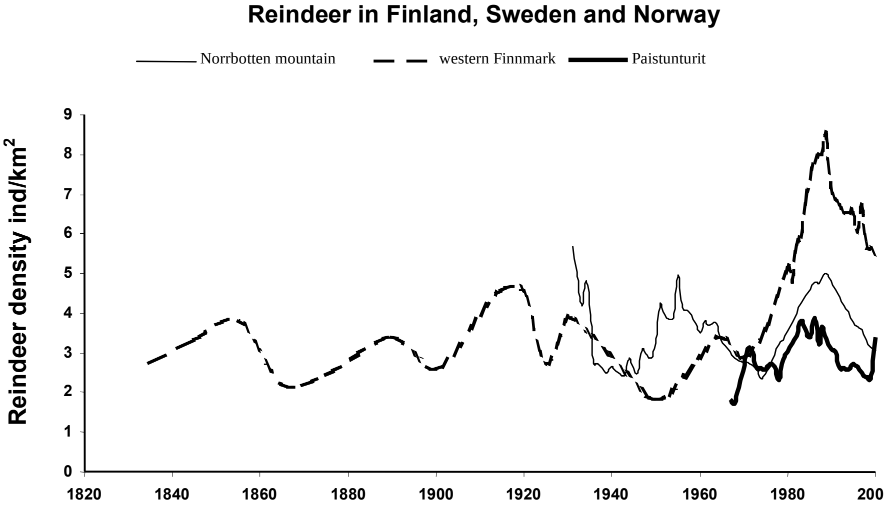


Fig. 11.1. Population dynamics of reindeer populations in mountain birch ecosystem in Finland, Sweden and Norway

winter feeding were only available to a limited extent. Nowadays, reindeer populations are managed by modern methods. Despite the change in herding practises, reindeer populations in the Paistunturin co-operative herding district, in the Norrbotten mountain population and in the western Finnmark population showed density variations typical for a traditionally managed reindeer population. However, the reasons for the population fluctuations may be different in different time periods, since condition of winter pastures, an important determinant of reindeer population dynamics, is better in the earlier than in the later period (Kumpula 2001).

11.4 Protection of Pastures in the Mountain Birch Zone

11.4.1 Analysis and Synthesis of the Effects of Reindeer Grazing on Different Vegetation Components

Reindeer grazing and its effects on pasture quality were studied in enclosures with controls (see enclosed CD for more methodological details). The variables measured were birch height, foliage biomass, seedling number and plant biomass or plant coverage of other pasture components, particularly lichen, dwarf shrubs, sedges and grasses. Most studies have measured lichen biomass or coverage. Lichens have high digestibility and they are the main natural source of forage for the reindeer in the winter season.

Two major patterns have emerged (Fig. 11.2). First, lichen coverage was reduced in grazed areas. Second, the other pasture components exhibited

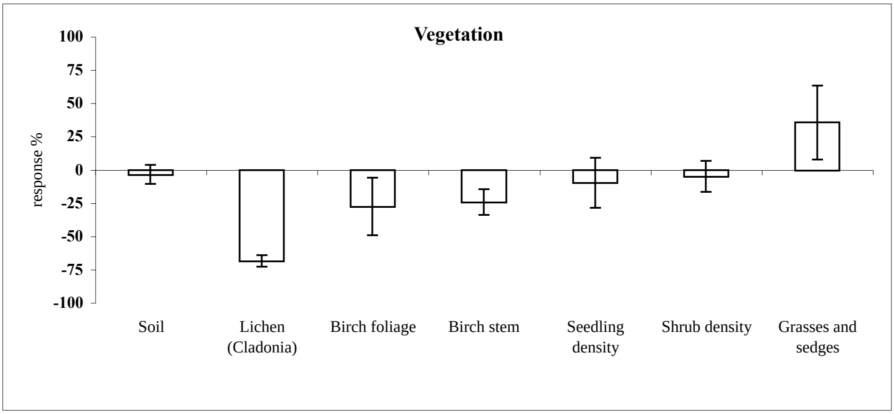


Fig. 11.2. Response of various pasture components to reindeer grazing in the Scandinavian mountain birch zone. Data summarize results of 38 independent field studies

highly variable responses to reindeer grazing. Birch often tended to have lower coverage or biomass, lower height and lower seedling density in grazed areas (but cf. Chaps. 4 and 17). Grasses tended to have a higher coverage and biomass in grazed areas.

The variability in the observed response to grazing might be due to different reindeer densities or differences in productivity or herding practices between the northern and southern parts of the reindeer herding area. However, we could not find any such clear differences between the northern and southern areas (Fig. 11.3).

The effect of reindeer grazing on lichen pasture is negative, but does not show a clear relationship with reindeer density above the level of 2 individuals/km^2 (Fig. 11.3). Evidently, lower grazing pressure is needed to achieve a successful recovery of lichen pasture. For the other vegetation components, the effects of reindeer are much more variable, suggesting that the rate of recovery is dependent on local conditions (productivity, precipitation, length of the growing season). Thus, suggestions for pasture management (see Chap. 19) should be applied with caution and take local conditions into account (e.g. Stark 2002).

Unfortunately, some variables measured in grazing impact studies may be too inaccurate to reveal relevant information both from the plant ecological and reindeer foraging perspectives. The total foliage biomass of mountain birch can be rather high even in cases when the regeneration of birches is close to zero. At the same time, the summer grazing pressure on the birch foliage available to reindeer (i.e. that in the layer 0–130 cm above ground) can be very high (Helle 2001; see also enclosed CD, Figs. 11A and 11B). To understand the impacts of reindeer grazing on birch regeneration and sapling establishment, foliage biomass in mature trees and saplings should be measured and reported separately, as well as that below breast height (130 cm) and above it. Furthermore, controlled experiments like those reported in Chapter 10 are needed to estimate the time (in years) that birch saplings need in order to reach the height when they become less susceptible to damage from reindeer. It should be remembered that mountain birch seedling growth is often very slow (cf. Chaps. 5 and 10).

The potential impacts of reindeer on birch will undoubtedly be underestimated if the possibility of simultaneous defoliation by insects is ignored. In many parts of the Fennoscandian mountain birch zone, it is indeed highly probable that the birches are subjected to both reindeer grazing and insect outbreaks (see Chaps. 9 and 12). The latter chapter describes in more detail the effects of reindeer on the regeneration cycles of different birch forest types after insect outbreaks (cf. also Lehtonen and Heikkinen 1995).

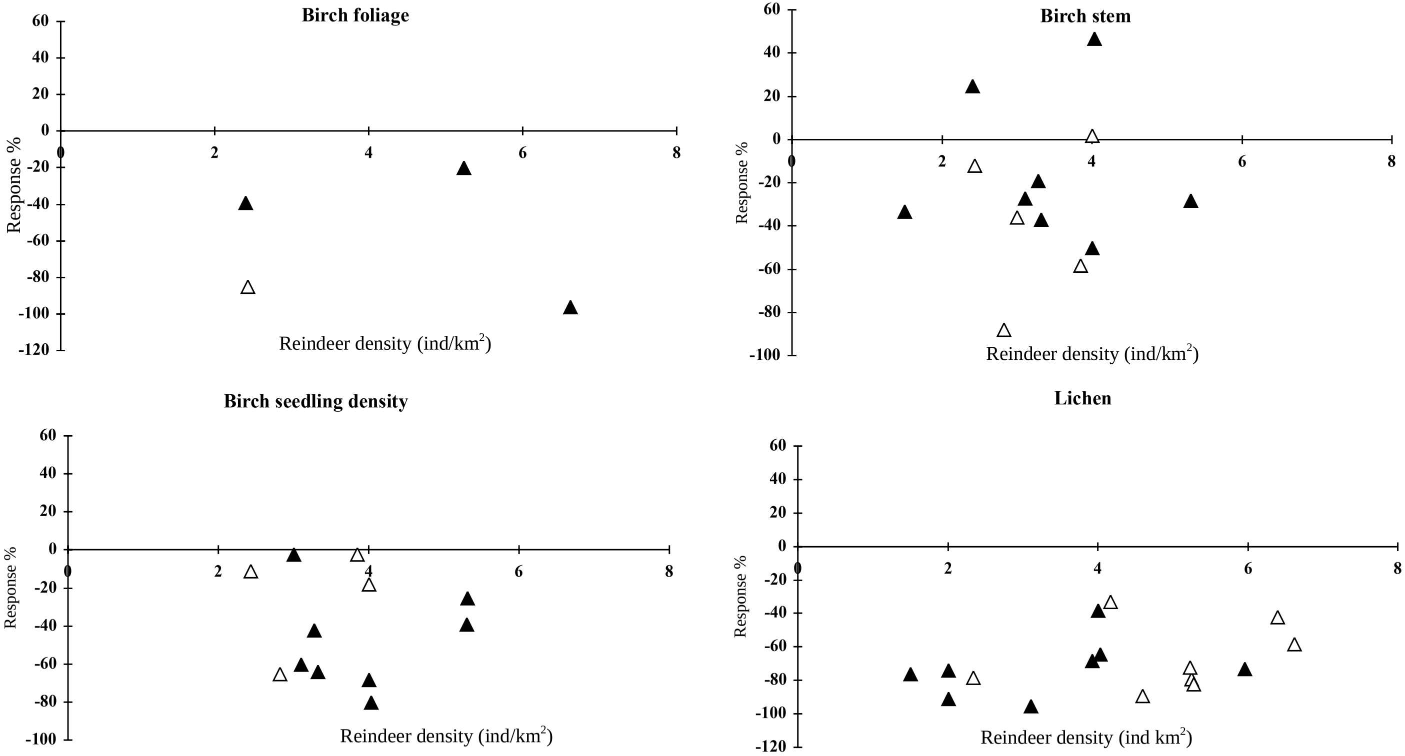


Fig. 11.3. Scatter plots illustrating relationships of reindeer density with responses of mountain birch foliage, stem growth, seedling density and lichen coverage to reindeer grazing. Densities are based on summer populations and total pasture area, i.e. no pasture rotation is assumed. *Filled triangles* indicate Norwegian or Swedish Sámi village or Sámi-dominating Finnish co-operative herding districts. *Open triangles* indicate Finnish-dominating co-operative herding districts in southern Finnish Lapland

11.4.2 Northernmost Norway as a Case Study of the Overall Effects of Reindeer Grazing on Vegetation

In the county of Finnmark, the cover and thickness of lichen mats vary a great deal in different regions. In 1999, parts of western and northern winter grazing districts in inner Finnmark showed very small lichen reserves left, and a large part of the ranges dominated by lichens in 1961 and 1973 was covered by dwarf shrubs, dwarf birch, grasses, mosses, bare humus and gravel. For instance, in Maze, the dwarf birch–lichen mountain heaths with lichen cover of more than 50 % have declined from about 30 % (1961) to 3.5 % (2000) of the total area (Tømmervik et al. 2004; Chap. 17). On the other hand, the dwarf birch *Empetrum–Myrtillus* mountain heaths without lichen or with reduced lichen cover have increased from 9.4 to 28.2 % of the total area.

In north-eastern Finnmark, the main winter grazing vegetation – dwarf shrub woodland with lichens (25–100 %) and dwarf birch–mountain crowberry heaths with lichen cover over 50 % – was reduced in the period from 1973–1999 mainly due to air pollution, but the decrease has not been as large as in Maze (Tømmervik et al. 1998; Chap. 4). The largest area of lichen reserves (often ungrazed) was found in the southernmost and easternmost parts of the county of Finnmark, in spite of being amongst the ranges most influenced by the Kola Cu-Ni smelters (Tømmervik et al. 1998). The reasons for this have been, amongst others, strict pasture rotations and low reindeer densities compared to the western districts of Finnmark. The lichen mats in forests of the Pasvik River valley are in parts so thick that net production does not take place. Lichens are dying off at the base at the same rate as they are growing at the top. The standing mass of lichen in these mats is more than 1500 g/m^2. The highest annual production per unit area is purported to be at a standing mass of lichen of 500–700 g/m^2. It would be good management practice to graze these pastures more heavily (cf. Chaps. 16 and 24). This may give room for much needed protection of the pastures in other parts of the district. However, the average carcass weight and density of reindeer (reindeer/km^2) were stable in the eastern districts of Finnmark during the period 1973–2000.

In Målselv (county of Troms), the proportion of lichen-poor heath dominated by dwarf birch, mountain crowberry and bilberry increased from 23.9 % (1978) to 30.0 % (1990), possibly due to heavy grazing by reindeer and sheep or military activities. From 1990–1999 the proportion of this vegetation type was reduced from 30.0 to 27.1 % while the lichen-rich (cover more than 30 %) heath dominated by dwarf birch and mountain crowberry increased in the same period, albeit its absolute coverage was 2.9 % (see Chap. 17).

Acknowledgements. We thank Asta Sipola and Tuomo Raunistola for the Finnish and Swedish reindeer census data. The first author appreciates the discussions with Otso Suominen and Helena Ruotsala.

References

Bråthen KA, Oksanen J (2001) Reindeer reduce the biomass of preferred vascular plants over the summer: some preferred plants still dominate the community. J Veg Sci 12:473–478

Gaare E (1997) A hypothesis to explain lichen–*Rangifer* dynamic relationships. Rangifer 17:3–7

Gaare E, Tømmervik H (2000) Monitoring of lichen grazing areas in Finmark. NINA Assignment Report, 638:1–33

Helle T (2001) Mountain birch forests and reindeer husbandry. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris, and Parthenon, New York, pp 279–291

Kumpula J (2001) Productivity of the semi-domesticated reindeer (*Rangifer t. tarandus* L.) stock and carrying capacity of pastures in Finland during 1960–1990's. Acta Univ Oulu Sci Rerum Nat A 375:1–44

Lee SE, Malcolm CP, Lee JA, Ingold T, Kurttila T (2000) Regional effects of climate change on reindeer: a case study of the Muotkatunturi region in Finnish Lapland. Polar Res 19:99–105

Lehtonen J, Heikkinen RK (1995) On the recovery of mountain birch after *Epirrita* damage in Finnish Lapland, with a particular emphasis on reindeer grazing. Ecoscience 2:349–356

Moen J, Danell O (2003) Reindeer in the Swedish mountains: An assessment of grazing impacts. Ambio, 32:397–402

Manseau M, Huot J, Crête M (1996) Effects of summer grazing by caribou on composition and productivity of vegetation: community and landscape level. J Ecol 84:503– 513

Nellemann C (1996) Terrain selection by reindeer in late winter in central Norway. Arctic 49:339–347

Post E, Stenseth NC (1999) Climatic variability, plant phenology, and northern ungulates. Ecology 80:1322–1339

Putkonen J, Roe G (2003) Rain-on-snow events impact soil temperatures and affect ungulate survival. Geophys Res Lett 30:1188

Riseth JÅ (2000) Sámi reindeer management under technological change 1960–1990: implications for common-pool resource use under various natural and institutional conditions. A comparative analysis of regional development paths in west Finnmark, north Trøndelag, and south Trøndelag/Hedmark, Norway. Department of Economics and Social Sciences, Agricultural University of Norway, Ås

Sandström, P., Granqvist Pahlén T, Edenius L, Tømmervik H, Hagner O, Hemberg L, Olsson H, Baer K, Stenlund T, Brandt LG, Egbert M (2003) Conflict resolution by participatory management: Remote sensing and GIS as tools for communicating land use needs for reindeer herding in northern Sweden. Ambio 8:557–567

Stark S (2002) Reindeer grazing and soil nutrient cycling in boreal and tundra ecosystems. Acta Univ Oulu Ser A Sci Rerum Nat 382:1–31

Suominen O (1999) Mammalian herbivores, vegetation and invertebrate assemblages in boreal forests: feeding selectivity, ecosystem engineering and trophic effects. Ann Univ Turku A II 122:1–26

Suominen O, Olofsson J (2001) Impacts of semi-domesticated reindeer on structure of tundra and forest communities in Fennoscandia: a review. Ann Zool Fenn 37:233–249

Tømmervik H, Johansen ME, Pedersen JP, Guneriussen T (1998) Integration of remote sensed and in-situ data in an analysis of the air pollution effects on terrestrial ecosystems in border areas between Norway and Russia. Environ Monit Assess 49:51–85

Tømmervik H, Johansen B, Tombre I, Thannheiser D, Høgda KA, Gaare E, Wielgolaski FE (2004) Vegetation changes in the Nordic mountain birch forest: the influence of grazing and climate change. Arct Antarct Alpine Res 36:322–331

Virtanen R (2000) Effects of grazing on above-ground biomass on a mountain snowbed, NW Finland. Oikos 90:295–300

12 Long-Term Influence of Herbivores on Northern Birch Forests

O. Tenow, H. Bylund, A.C. Nilssen and P.S. Karlsson

12.1 Introduction

Species of many insects, some mammals and birds feed on buds and leaves of mountain birch, *Betula pubescens* ssp *czerepanovii* (Haukioja and Heino 1974; Brittas 1988; Neuvonen et al. 2001). Of these species, two geometrid moths, *Epirrita autumnata* (autumnal moth) and *Operophtera brumata* (winter moth), are the most important because of their large-scale and long-term influence on mountain birch ecosystems. The earliest report on an outbreak is by Ruge in the 1700s from Nord-Valdres in southern Norway (see references in Tenow 1972), and the next is of a mass occurrence in 1852 at Alta in northern Norway. Since then, 15 outbreak periods have been documented and a sixteenth is currently (2004) going on (Tenow 1972; Ruohomäki et al. 2000; Helena Bylund, pers. observ). Conclusively, these outbreaks are indigenous and ancient phenomena in the mountain birch/insect system. The population fluctuations are more or less synchronized, the caterpillars causing defoliating outbreaks about every 9–11 years (Tenow 1972; Haukioja et al. 1988; but cf. Chap. 9).

The consequences of an outbreak depend on several circumstances, primarily what type of birch forest is attacked, i.e. heath forests mainly with polycormic (multi-stemmed) trees which propagate in particular by basal sprouts (cf. Chap. 1), or meadow forests on richer sites with monocormic (single-stemmed) trees propagating mainly by seeds (Sandberg 1963; cf. Holm 1994). Circumstances influencing the severity of an outbreak are age of the forest and previous abiotic and biotic stresses. In the case of severe defoliations, many monocormic trees die, as do many stems of polycormic trees. In surviving stems the mortality of shoots is heavy. Stems and trees that survive benefit from reduced competition and will soon produce new leaves. However, more important is the long time it takes for basal sprouts and seedlings to grow and replace the leaf-carrying canopy that was lost with stems and tree individuals that died (Tenow and Bylund 2000; Tenow et

---

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

al. 2004). Here, the presence or absence of heavy grazing by reindeer or sheep is of importance.

Severe outbreaks thus have a long-term influence on mountain birch ecosystems. This influence occurs on an ecological time scale. A great capacity to propagate vegetatively by sprouts is considered to be of strong selective value in a stressful environment (Vaarama and Valanne 1973). In this respect, polycormic birch resembles the dwarf birch (*Betula nana*). It has been shown that this capacity is derived from introgression of *B. nana* genes into *B. pubescens* (Vaarama and Valanne 1973; Thórsson et al. 2001; Chap. 1). In the process of introgression, which is assumed to be still going on, repeated mass attacks of *E. autumnata* may act as one of several forcing factors (Vaarama and Valanne 1973; Kallio and Mäkinen 1978; cf. Verwijst 1988). Thus, there may also be a long-term influence on an evolutionary time scale.

This chapter summarises in a conceptual model the influences of herbivory on birch forests on an ecological time scale. It starts with a case study, which is then applied to northern Fennoscandia as a whole, and ends with some comments on possible effects of an anticipated anthropogenic change of the climate.

12.2 Lake Torneträsk–Abisko Valley Area: A Case Study

Lake Torneträsk (68°20′N, 19°00′E, 342 m a.s.l.) with a length of 65 km and width of 10 km is one of the largest lakes in northern Sweden. The wide Abisko valley joins the southern side of the lake. The area is surrounded by 1000- to 1700-m-high mountains and has a climate that is intermediate between the maritime climate at the Norwegian coast to the west and the continental climate in the interior of northern Fennoscandia. The Abisko valley has a low precipitation (about 300 mm/year), while the southwest-facing slopes of the northern side of Lake Torneträsk are exposed to westerly winds (precipitation about 600 mm/year) (Sonesson and Hoogesteger 1983). Due to this difference and a warm slope, the northern side of the lake is dominated by meadow birch forests, whereas in the Abisko valley heath birch forests dominate (Sandberg 1963, 1965; Sonesson and Hoogesteger 1983; cf. Chap. 5).

12.2.1 Outbreak in a Heath Birch Forest

The Abisko valley was completely defoliated by *E. autumnata* in 1954–1955. In the peak year 1955, larval abundance reached about 160 caterpillars/100 leaf-carrying shoots (Tenow et al. 2001). As a result, more than 80 % of the shoot population of the forest died in 1956 (Tenow and Bylund 2000). There was a gradient in mortality from the outer part of the valley where most trees and stems survived to the inner part where many trees were killed (Palm 1959; Tenow 1975). There were also stands untouched by the outbreak, e.g. along the lower part of the River Abiskojokk (Tenow 1975). *E. autumnata* eggs on average freeze at air temperatures of about –36 °C in midwinter and at about –29 °C in late winter (Nilssen and Tenow 1990; cf. Chap. 9). In the 1954–1955 winter, temperatures below –36 °C killed the eggs in a cold-air "lake" accumulated along this part of the river and, hence, protected the stands from being defoliated (Tenow 1975; Tenow and Nilssen 1990; Tenow et al. 2001).

Birch trees have two types of leaf-carrying shoots: long shoots and short shoots (Maillette 1982) in a proportion of about 1:10 at Abisko (Tenow and Bylund 2000). In the late summer of 1955, surviving short shoots in the Abisko valley either grew greatly enlarged leaves or were transformed to long shoots and, importantly, defoliation elicited the growth of dormant buds on surviving stems and triggered basal sprouts on weakened or dying stems (Tenow 1956; Tenow and Bylund 2000). Axillary short shoot buds on long shoots constituted a base for the restoration of the short shoot population. The production of basal sprouts culminated in 1956–1957 and ceased in the 1960s (Tenow et al. 2004). Since then, the shoot population has increased and basal sprouts have grown to new stems, substituting killed old stems. It is thus possible to identify rejuvenating outbreaks in heath birch forests and date them from the distinct cohorts of sprouts they trigger. Kullman (1991), in contrast, interpreted the time span between cohorts as outbreak periods during which stems were killed by *E. autumnata*. The cohorts in his study were contemporary with severe outbreaks and the gap between them was a period when no outbreak was reported (Tenow 1972).

The recovery of the forest was monitored until 1988 at two sites in the valley (Tenow and Bylund 2000). In 1988, the forest at both sites had recovered to about 75 % of the number of shoots making up the foliage prior to the outbreak. This was, however, achieved in different ways. In the outer part of the valley, stem mortality was low after the outbreak (Tenow 1975). In 1988, 80 % of the shoot population occurred in the crowns of surviving stems and 20 % on the now about 30-year-old stems that started as basal sprouts. In the center of the valley, stem mortality was higher (Tenow 1975). Here, about 40 % of the shoots occurred in the crowns of surviving stems, while 60 % was carried by the stems growing out as basal sprouts (Tenow and Bylund 2000). Most of these stems were triggered by the outbreak. However, some sprouts were produced before the outbreak, but had apparently been suppressed by older stems until some old stems were killed in the mid-1950s (Tenow et al. 2004). In 1988, these previously suppressed stems were indistinguishable by eye from the directly outbreak-triggered sprouts. Young trees of seed origin were few (Tenow and Bylund 2000).

It has been estimated that the forest at the two sites will be fully recovered in about 75 years from the initial damage, given that no new large perturbations occur meanwhile (Tenow and Bylund 2000; Chap. 5). The different recovery patterns imply that the forest in the central part of the valley became radically rejuvenated while that in the outer part was not (Tenow et al. 2004).

In the Abisko valley, the *E. autumnata* population builds up to higher densities in old stands than in young stands and individual old birch trees carry higher larval populations than young trees (Bylund 1997). This suggests that primarily old forests are prone to being severely defoliated and, hence, rejuvenated. The stem population structure indicates that there have been three periods of sprout production during a 140-year period (Sonesson and Hoogesteger 1983; Tenow et al., unpubl. data). If all these were triggered by *E. autumnata* outbreaks, this suggests ca. 60–70 years between severe outbreaks. This fits well with the 75-year recovery period estimated for the 1954–1955 outbreak (cf. above). In conclusion, the turnover time of a forest stand from one rejuvenating outbreak to the next will be many decades in the Abisko valley (Bylund 1995). In the meantime, no severe outbreak will probably occur. Severe outbreaks will instead happen elsewhere in the Lake Torneträsk area, i.e. where stands have reached the critical age structure with old stems dominating (Tenow and Bylund 1989).

12.2.2 Outbreak in a Meadow Birch Forest

In 1965, the old birch forest (cf. diameter classes, Sonesson and Hoogesteger 1983) on the northern side of Lake Torneträsk became severely defoliated, in this case by caterpillars of *O. brumata* (Tenow 1972; Tenow et al. 2001). In the start year 1964, leaves were completely consumed in a low–middle altitude position of the slope. The defoliated zone was mapped, but the caterpillar density is not known. This zone coincided with the zone of highest average June air temperature and first budbreak in early summer (Tenow et al. 2001). Probably, egg hatch and budbreak in this zone match each other optimally for a population buildup. In 1965, the outbreak spread upslope from the middle zone, which became defoliated for a second year. Larval density was about 150 caterpillars/100 shoots, i.e. about as many as in the Abisko valley in 1955 (Tenow et al. 2001). As a result, the many monocormic birch trees in this zone were killed (Sonesson and Hoogesteger 1983).

In the lower- and uppermost parts of the slope, the foliage had recovered fully after 25 years (1965–1990), whereas in the middle zone the recovery was insignificant (2 %) (Tenow et al. 2001). Most of this zone still looks more like a meadow than a forest. In comparison, the forest in the Abisko valley had recovered to approximately 50 % in a comparable time period (Tenow and Bylund 2000). A reason for this difference might be the generally different reproductive strategies of the polycormic and monocormic growth forms of the mountain birch, i.e. rejuvenation by sprouts and regeneration from seeds, respectively (Sandberg 1963; Holm 1994; cf. Chap. 5). In the Abisko valley, basal sprouts started to grow immediately after the outbreak and could profit from already developed root systems. On the northern side of Lake Torneträsk, recovery had to rely mainly on a hazardous establishment and growth of seedlings (cf. Kullman 1993; Molau and Larsson 2000; Karlsson and Weih 2001). Herds of semi-domesticated reindeer pass through the Abisko valley and along the northern side of the lake during their annual move to and from their alpine grazing grounds (cf. Chap. 11), on average about 4000 animals on each side according to the administration of the County of Norrbotten. During these passages, the animals preferably browse leaves of mountain birch (cf. Helle 2001). After the outbreak in the Abisko valley, reindeer browsing on the young sprouts was sometimes substantial (Tenow 1996). However, recovery continued. One explanation could be that reindeer often only rip off tip leaves, leaving lower leaves intact. In addition, in the fast-growing bouquets of sprouts, the outer sprouts may protect the inner ones. Hence, one important reason for the absence of regeneration on the northern side could be that seedlings are more vulnerable to reindeer browsing than rapidly growing sprouts (Lehtonen and Heikkinen 1995; Tenow 1996; cf. Kallio and Lehtonen 1973). Also, the northern side has a deeper snow cover in winter than the Abisko valley, which favours the growth of vole populations during peak years and, thus, increased gnawing of bark (cf. Oksanen and Oksanen 1992). Thus, damage from small mammals may have contributed to the absence of recovery.

12.3 Northern Fennoscandia

On the eastern side of the Scandes, the mountain birch forests are mainly heath forests dominated by polycormic trees; on the western side, fresh heath and more nutrient-rich meadow birch forests of monocormic trees dominate (Hämet-Ahti 1963; cf. Chap. 1). In the following, forests with mostly monocormic trees will be called monocormous, and forests and stands dominated by polycormic trees (i.e. heath forests) analogously polycormous forests.

The outbreak distributions of the two moths meet along the Scandinavian mountain chain, *O. brumata*'s in the richer forests on the western side and *E. autumnata*'s on the eastern side. One exception is the Finnmarksvidda highland plain where *E. autumnata* eggs usually do not survive the very low winter air temperatures. Outbreaks of *E. autumnata* also occur regularly in upper parts of the mountain birch zone on the western side. Occasional extensions of outbreaks of *O. brumata* to the eastern side may occur; however, the only documented one is that in the Lake Torneträsk area. The outbreaks of *E. autumnata* and *O. brumata* at Lake Torneträsk are details in the total distributions of outbreaks. At the same time they may reflect patterns and traits in the total distributions.

12.3.1 Forest Age and Outbreaks

In the Abisko valley, primarily old stands and trees of the polycormous forest were attacked by *E. autumnata*. Similarly, in northern Fennoscandia in total, both east and west of the watershed, mostly old trees and stands seem to be attacked by *E. autumnata* (Tenow 1972 and references therein; Ruohomäki et al. 1997). Probably this also applies to stands of monocormic birch (Tenow 1972). The frequent lichen cover, bark cracks and flakes on stems and branches on old trees offer microsites suitable for egg deposition and may also protect overwintering eggs from, e.g. predation, and therefore favour population buildup (Bylund 1997).

There is no documentation of a similar tendency of *O. brumata* outbreaks in the Scandes, except in the Lake Torneträsk area. However, a series of studies of *O. brumata* females outside the mountain birch region suggest that old trees are preferred for egg-laying (Uffeln 1916; Axelsson et al. 1975; MacPhee et al. 1988; Graf et al. 1995). Applied to mountain birch, it seems likely that *O. brumata*, like *E. autumnata*, is more outbreak prone in older than in younger mountain birch forests.

12.3.2 Forest Damage and Recovery

There are many reports from both sides of the Scandes that birch forests have been severely damaged and even killed by insect outbreaks. Often, reports do not mention type of forest, growth form of birches or make remarks on signs of recovery. Examples from the eastern side of the Scandes, where *E. autumnata* is the attacker, are both from the mountain birch zone and from birch stands far outside the mountains (Tenow 1972 and references therein). Where recovery is indicated, this is from basal sprouting of polycormic trees (Fig. 12.1) (southern Swedish Lapland: Holmgren 1905 and Kullman 1991; northeastern Finland: Kallio and Lehtonen 1973). In northeastern Norway, an *E. autumnata* outbreak in 1964–1965 caused heavy stem mortality (Solheim 1976). In 1972, extensive growth of basal sprouts was observed in the same damaged forest (Günther Schmidt, pers. comm.). In the few documented attacks of *E. autumnata* in monocormous forests on the eastern side of the mountains, long-lasting devastation seems to have occurred (vegetation map no. 5, Kebnekaise: Vistasvagge, Torne Lappmark, Sweden; Lehtonen and Heikkinen 1995). In some areas, recovery of polycormous stands has also failed as in northeastern Finland after the 1964–1965 outbreak of *E. autumnata*. In this case, failure was due mainly to root rot (Lehtonen 1987; Lehtonen and Heikkinen 1995).

Examples from the western side cover areas from the watershed to the coast and comprise attacks of *E. autumnata* at higher and of *O. brumata* at

Fig. 12.1. Polycormic birch with stems killed by *Epirrita autumnata* recovering from basal sprouts 9 years after the outbreak, Pulsujärvi, Torne Lappmark, northern Sweden, 2002. (Photo: H. Bylund)

lower altitudes (Tenow 1972 and references therein). In inner Troms, northern Norway, close to the watershed in the valley called Dividal, polycormous stands which were defoliated in 1964–1965 recovered by basal sprouts in 1974 (Vorren and Engelskjøn 1974). In two other localities further to the northwest, stands of monocormic trees were damaged in 1945, probably by *E. autumnata*. In one of them, regrowth was good in 1963, mostly from seedlings (Fig. 12.2). In the other locality, no signs of recovery were seen in 1963 (Tenow 1972). Reports on birch stands being badly damaged or killed by *O. brumata* are mostly from coastal areas. In 1898–1900, the birch forest on the island called Tromsøya and surroundings was completely defoliated and assumed killed (see references in Tenow 1972). However, photographs taken some years later show that most stands greened again (Christensen and Pedersen 1995). Even before the outbreak, regrowth of stands was hampered by cattle browsing (Schneider 1902). When the cattle holding was strongly reduced, the forest of mainly monocormic trees recovered. In other instances, no later fate of "killed" stands was reported (Tenow 1972 and references therein).

In the same way as in the Lake Torneträsk area, outbreaks may shift areas as other stands become vulnerable to severe defoliation. In the area of the Dividalen valley, outbreaks occurred in the neighbouring valley Rostadalen in 1944–1946 (Tenow 1972), in the valley of Anjavass River, a subsidiary to the

Fig. 12.2. A stand of monocormic birch with trees killed by *Epirrita autumnata* (or *Operophtera brumata*) recovering with young trees of seed origin 18 years after the outbreak. Likkavarre, Sørdalen, inner Troms, Norway, 1963. From Tenow (1972)

Dividalen in 1964–1965 (Vorren and Engelskjøn 1974), and in the upper Dividalen in 1994 (Tømmervik et al. 2001).

12.3.3 Interaction with Reindeer and Sheep

Most forests with high tree mortality seem to have been dominated by monocormic trees. Two comprehensive studies in northern Fennoscandia deal with the interaction between *E. autumnata* and reindeer. After the 1964–1965 outbreak in northeasternmost Finland, it was demonstrated that individual monocormic birch trees had a low capacity to recover and that vast areas of monocormous stands at the forest limit were killed (Kallio and Lehtonen 1973, 1975; Lehtonen 1987). Over the surveyed time period (1970–1991), reforestation from seeds was slow. From exclosure experiments it was shown that this was due to reindeer grazing (Lehtonen and Heikkinen 1995). Possibly also damage made by small mammals contributed. Some parts of the devastated area have turned into heaths with only scattered trees and others into treeless tracts expanding the adjacent alpine tundra (Kallio and Lehtonen 1973).

The second study concerned forests in northern Norway and Finland, on both sides of the watershed (Oksanen et al. 1995). It contained analyses of forest physiognomy in relation to climate and reindeer grazing and embraced areas from the Finnmarksvidda to the coast with and without intensive summer grazing. Results suggest that extensive woodlands sparsely grown with monocormic birch in the vicinity of the forest limit are the product of an interaction between *E. autumnata* and reindeer. As in the first study, birch thickets started to grow where fencing excluded summer grazing.

Grazing by sheep (and cattle) is severe in large areas at low altitude along the Norwegian coast (Hämet-Ahti 1963; Oksanen et al. 1995) where also *O. brumata* outbreaks occur (Tenow 1972, 1996). In their study, Oksanen et al. (1995) did not consider *O. brumata* outbreaks, although they found open sheep-grazed woodlands with monocormic birch of about the same type as grazed by reindeer. Originally, parts of these woodlands most probably were opened by tree felling. However, it is likely that also sheep grazing of seedlings has contributed to keep forests open after severe *O. brumata* outbreaks.

12.4 Generalization

The birch forest ecosystems of the entire northern Fennoscandia are more variable and complex than those in the Lake Torneträsk area. Human use of the forests is more diverse and intensive, although the forests around Lake Torneträsk have also been exploited with various intensities over time (Emanuelsson 1987). Also sheep, cattle and goats may interact with outbreaks. The complexity is further increased by the presence of additional outbreaks of insects (Tenow 1996; Neuvonen et al. 2001). One such group is several species of leaf-mining *Eriocrania* moths which primarily attack young birch stands all over northern Fennoscandia (Bylund and Tenow 1994; Tenow 1996). Another species is the bud-mining *Argyresthia retinella* (birch bud moth), which at present damages birch stands along the north Norwegian coast (Tenow et al. 1999). In spite of these complications, results may warrant a generalization.

12.4.1 A Conceptual Model

E. autumnata outbreaks in polycormous forests trigger sprouts which rejuvenate the forest (cf. Haukioja and Koricheva 2000) and create a stem age structure with distinct cohorts. The stem age structure in the Abisko valley indicates a periodicity of these rejuvenating events at roughly 70-year intervals. Probably, some monocormous forests have a turnover in similar cycles driven by *O. brumata* (or *E. autumnata*), given that no intensive ungulate grazing occurs. Results and information may be synthesized into a conceptual model (Fig. 12.3). In the diagram, the young forest stage is common to the two cycles for three reasons: (1) sometimes polycormic birch may propagate by seeds and monocormic ones by sprouts, (2) at some sites there are mixtures of polycormic and monocormic birch, and (3) forced by a changing climate, the one forest type may transform into the other.

Additional components not indicated in the model are, e.g., small mammals and *Hylecoetus dermestoides*, a beetle attacking weakened birch trees.

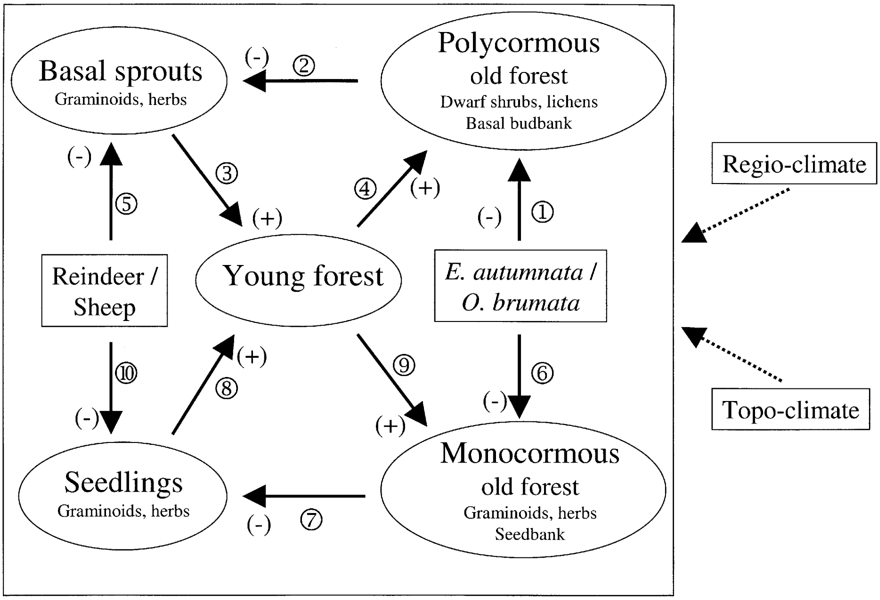


Fig. 12.3. Conceptual model of the forcing of mountain birch forests by herbivores. Upper turnover loop (*arrows 2–4*) starting with an outbreak mostly by *Epirrita autumnata* (*arrow 1*) may take about 60–100 years. Meanwhile, the moth population cycle revolves about six to ten times with increasing amplitude until a new outbreak perpetuates the loop. Grazing by ungulates (*arrow 5*) may sometimes delay this loop. Lower loop (*arrows 7–9*) goes on for an approximately equally long time period, forced by *Operophtera brumata* (or *E. autumnata*) (*arrow 6*). Grazing (*arrow 10*) may interrupt the loop for a long time. See also text

Larvae of *H. dermestoides* tunnel horizontally under the bark of stems and in this way cut off conductive tissues, thus killing old stems. Small mammals kill sprouts and seedlings by gnawing off the bark. A delay may also arise from root rot which spreads from mother roots to sprouts connected to the old root (young forest compartment). Outbreaks of the *A. retinella* moth affect forests strongly at present (2004) (Tenow et al. 1999; Elverum et al. 2003). Too limited reserves for growth due to cold summers may hamper recovery (Kallio and Lehtonen 1975).

Severe outbreaks are fast events (Fig. 12.3, arrows 1 and 6), occurring over a few years. By killing or damaging old trees and stems, the outbreak decreases the negative influence (apical dominance, competition) of the old trees and stems (arrows 2 and 7). As a result, sprouts are triggered. A grass-dominant phase, possibly negative to the establishment of seedlings (cf. Holmgren 1905; Chap. 4), and the gradual shading away of grasses by a new foliage (arrow 8) may go on for 10–30 years (Holmgren 1905; Kalliola 1941; Sandberg 1963; Lehtonen and Yli-Rekola 1979). At one and the same site, entire cycles from one defoliation-prone old forest stage to the next take many decades, in time equivalent to about one human generation or longer. On a landscape scale, this may create a mosaic of stands at different ages in accordance with the mosaic-cycle concept of ecosystems (Remmert 1991). In this respect, the result is equivalent to that of large-scale cuttings as simulated in Chapter 22 (Fig. 22.4).

Where intensive grazing by ungulates occurs (arrow 10), the monocormous forest cycle is halted at an open woodland or a meadow stage.

12.4.2 Forests Without Outbreaks

In northern Fennoscandia as in the Abisko valley, there are local birch stands along river valleys and around lakes which are protected by cold air accumulations in winter (Tenow 1972; Kallio and Lehtonen 1973). There is also a whole region, the Finnmarksvidda, where air temperatures almost every winter fall below the critical temperature for the survival of *E. autumnata* eggs (Tenow 1983; Tenow and Holmgren 1987; Tenow and Nilssen 1990). Here, polycormous forests dominate (Hämet-Ahti 1963). Frequent freezings prevent high larval populations from building up and, hence, protect these forests from being defoliated (Tenow 1972, 1996; Tenow and Nilssen 1990). Therefore, *E. autumnata* has not been an important rejuvenating factor in this area. Instead, extreme frost, wind and drought may have acted as substitutes for *E. autumnata* (cf. Barth 1862). This conclusion is supported by the unimodal age distribution of birch stems in the Finnmarksvidda region, which indicates randomly acting mortality factors and a mean stem age of about 80 years (see Chap. 3, Fig. 3.1).

In some valleys, the valley floor is devoid of birch although the valley on both sides is forested higher up. Fries (1913) discussed this “valley phenomenon" and proposed that low temperatures during winter prevented reproduction or growth of birch. Kullman (1981) instead argued that the forest on the valley floor in winter becomes immersed in a cold-air "lake" where *E. autumnata* eggs are killed by lethal temperatures. It has been shown that the suckering capacity of birch declines with age (Mikola 1942; Kauppi et al. 1988). Therefore, stands in the valley floor should have languished of old age due to the lack of rejuvenating outbreaks (Kullman 1981). However, specifically, the mountain birch retains its suckering capacity still in old age (Mikola 1942). Furthermore, the "valley phenomenon" described by Fries (1913) occurs in the upper part of valley bottoms, not far from the forest limit. At that altitude, egg-killing air temperatures (–36 °C and below) may never occur (cf. Holmgren and Tenow 1987). Nevertheless, it is likely that the absence of outbreaks in a polycormous forest may result in a degeneration of the forest (Haukioja and Koricheva 2000).

12.4.3 Mountain Birch Forest Regeneration Cycles in a Warmer Future

Updated assessments on global climate change present new and strong evidence that most of the warming observed over the last 50 years is attributable to human activities (IPCC Climate Change 2001). A continued increase in precipitation and surface air temperature is predicted, particularly at terrestrial high latitudes (cf. Chap. 1). Such changes may have profound effects on the mountain birch forest and on the mountain birch/*E. autumnata*/*O. brumata* systems. In model projections, a vertical lift of vegetation belts of several hundred metres has been predicted (Boer et al. 1990; Holten and Carey 1992; Kullman 2002; Skre et al. 2002). Probably, therefore, large areas above the present forest limit will be wooded with mountain birch. Depending on, e.g., freezing of saplings and reindeer grazing or not grazing, stands may grow up as monocormous, polycormous or a mixture of birch types and follow the loops of the conceptual model accordingly (Fig. 12.3). For monocormous stands, this may continue for some time (cycles) until environmental stresses, including *E. autumnata* outbreaks, have constrained birches to the polycormic growth form by forcing repeated basal sprouting. Thus, forest cycling will probably follow the polycormous forest cycle (upper loop, Fig. 12.3).

A warmer future with increased precipitation, better snow protection and mainly longer growing seasons (but see Chap. 4), as well as improved edaphic conditions, may at some localities imply a lasting amelioration and a gradual change of the forest type. The conceptual model (Fig. 12.3) allows for this possibility, i.e. a shift from the polycormous forest cycle (upper loop) to the monocormous forest cycle (lower loop).

After severe defoliation, mountain birch recovery seems more limited by carbohydrate than nitrogen reserves (cf. Karlsson and Weih 2003). The ability of birch to recover may thus depend on the size of the carbohydrate reserves and, thus, whether or not conditions were favourable for the building up of reserves during the year(s) prior to the outbreak. This idea is supported by the observation that the capacity to produce new shoots is higher after warm than after cool summers (cf. Kallio and Lehtonen 1973; Haukioja et al. 1985). An effect of warmer summers could thus be an increase in the ability of birches to recover from defoliation, e.g. by growing basal sprouts (upper loop, Fig. 12.3). However, it is uncertain whether birch will benefit from a warmer climate (cf. Chap. 8). One factor counteracting shoot production and seedling establishment could be an earlier dehardening of birch in spring and the increased risk of bud freezing at setbacks in weather (e.g. Skre et al. 2002; see also Chap. 6).

The production of seeds is resource-demanding which is why a rich seed year exhausts reserves and hampers subsequent growth and reproduction (Haglund 1905; Gross 1972; Karlsson et al. 1996). Therefore, mast seed years in a harsh mountain environment occur only at long time intervals (Holm 1994). In a climate with warmer summers, mast seed years may become more frequent (cf. Skre et al. 2002). It has been shown that seed production is reduced some years after a defoliating outbreak (Holm 1994; Karlsson and Weih 2003). Nevertheless, in the long run, more frequent seeding may enhance recruitment of young birch and promote recovery of birch forests after severe outbreaks, particularly in monocormous forests (lower loop, Fig. 12.3). This may also presuppose, e.g., favourable soil properties and temperatures, and soil exposed to seeding by disturbance of the ground vegetation (Weih and Karlsson 1999; Karlsson and Weih 2001).

Provided that outbreaks will still occur in a warmer future (cf. Chap. 9), *E. autumnata* and *O. brumata* outbreaks will probably extend into new areas. Forests on Finnmarksvidda and in topoclimatically cold areas along rivers and around lakes, previously protected by low winter air temperatures, may become open to *E. autumnata* outbreaks (Tenow 1996; Virtanen et al. 1998; Bylund 1999; Tenow et al. 2001). However, in a warmer climate, factors promoting birch growth and outbreaks may be counteracted by many abiotic and biotic factors in complex interactions (see Chaps. 5 and 9) which makes it difficult to foresee effects of a changed climate on the dynamics of the mountain birch/geometrid systems. Anyway, in Fennoscandia with its extension far into high latitudes and with mountains of high altitude, climate zones favourable to dynamic systems will probably still occur also in the future.

These scenarios presume a lasting warming. However, there may be a totally different turn of the climate. After an initial warming, a drastic cooling may follow with far-reaching consequences for northern ecosystems (Tenow et al. 2001 and references therein). The consequences of such a change have to be considered.

References

Axelsson B, Lohm U, Nilsson A, Persson T, Tenow O (1975) Energetics of a larval population of *Operophthera* spp. (Lep., Geometridae) in central Sweden during a fluctuation low. Zoon 3:71–84

Barth JB (1862) Saeregen foryngelsesmaade af birkeskoven (in Norwegian). Forh Vid Selsk Christiania 1861:113–116

Boer MM, Koster EA, Lundberg H (1990) Greenhouse impact in Fennoscandia – preliminary findings of a European workshop on the effects of climate change. Ambio 19:2–10

Brittas R (1988) Nutrition and reproduction of willow grouse *Lagopus lagopus* in central Sweden. Ornis Scand 19:49–57

Bylund H (1995) Long-term interactions between the autumnal moth and mountain birch: the roles of resources, competitors, natural enemies, and weather. PhD Thesis, Swedish University of Agricultural Sciences, Uppsala

Bylund H (1997) Stand age-structure influence in a low population peak of *Epirrita autumnata* in a mountain birch forest. Ecography 20:319–326

Bylund H (1999) Climate and the population dynamics of two insect outbreak species in the north. Ecol Bull 47:54–62

Bylund H, Tenow O (1994) Long-term dynamics of leaf miners, *Eriocrania* spp., on mountain birch: alternate year fluctuations and interaction with *Epirrita autumnata*. Ecol Entomol 19:310–318

Christensen P, Pedersen G (1995) Ishavsfolk, arbeidsfolk og fintfolk: 1900–1945 (in Norwegian). Tromsø gjennom 10000 år, vol 3. Tromsø Commune, 584 pp

Elverum F, Johansen TJ, Nilssen AC (2003) Life history, egg cold hardiness and diapause of *Argyresthia retinella* (Lepidoptera, Yponomeutidae). Norw J Entomol 50:43–53

Emanuelsson U (1987) Human influence on vegetation in the Torneträsk area during the last three centuries. Ecol Bull 38:95–111

Fries TCE (1913) Botanische Untersuchungen im nördlichsten Schweden. Akademische Abhandlung. Vetenskapliga och praktiska undersökningar i Lappland anordnade af Luossavaara-Kirunavaara Aktiebolag. Almqvist und Wiksell, Uppsala, Stockholm

Graf B, Borer F, Höpli HU, Höhn H, Dorn S (1995) The winter moth, *Operophtera brumata* L. (Lep., Geometridae), on apple and cherry: spatial and temporal aspects of recolonization in autumn. J Appl Entomol 119:295–301

Gross HL (1972) Crown deterioration and reduced growth associated with excessive seed production by birch. Can J Bot 50:2431–2437

Hämet-Ahti L (1963) Zonation of the mountain birch forests in northernmost Fennoscandia. Ann Bot Soc Vanamo 34(4):1–127

Haglund EE (1905) Ur de högnordiska vedväxternas ekologi (in Swedish). PhD Thesis, University of Uppsala

Haukioja E, Heino J (1974) Birch consumption by reindeer (*Rangifer tarandus*) in Finnish Lapland. Rep Kevo Subarct Res Stn 11:22–25

Haukioja E, Koricheva J (2000) Tolerance to herbivory in woody vs. herbaceous plants. Evol Ecol 14:551–562

Haukioja E, Niemelä P, Sirén S (1985) Foliage phenolics and nitrogen in relation to growth, insect damage, and ability to recover after defoliation, in the mountain birch *Betula pubescens* ssp. *tortuosa*. Oecologia 65:214–222

Haukioja E, Neuvonen S, Hanhimäki S, Niemelä P (1988) The autumnal moth in Fennoscandia. In: Berryman AA (ed) Dynamics of forest insect populations, patterns, causes, implications. Plenum Press, New York, pp 163–178

Helle T (2001) Mountain birch forests and reindeer husbandry. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and biosphere series 27. UNESCO, Paris, and Parthenon, New York, pp 279–291

Holm S-O (1994) Reproductive patterns of *Betula pendula* and *B. pubescens* coll. Along a regional altitudinal gradient in northern Sweden. Ecography 17:60–72

Holmgren A (1905) En insektshärjning och dess inflytande på vegetationen (in Swedish). Skogsvårdsföreningens Tidskrift 3:385–389

Holmgren B, Tenow O (1987) Local extreme minima of winter air temperature in high-latitude mountainous terrain. In: Alexandersson H, Holmgren B (1987) Climatological extremes in the mountains, physical background, geomorphological and ecological consequences. UNGI rapport 65. Department of Physical Geography, Uppsala University, pp 25–41

Holten JI, Carey PD (1992) Responses of natural terrestrial ecosystems to climate change in Norway. NINA Forskningsrapp 29:1–59

IPCC Climate Change (2001) Synthesis report. Third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

Kallio P, Lehtonen J (1973) Birch forest damage caused by *Oporinia autumnata* (Bkh.) in 1965–1966 in Utsjoki, N Finland. Rep Kevo Subarct Res Stn 10:55–69

Kallio P, Lehtonen J (1975) On the ecocatastrophe of birch forests caused by *Oporinia autumnata* (Bkh.) and the problem of reforestation. In: Wielgolaski FE (ed) Fennoscandian tundra ecosystems, part 2. Animals and systems analysis. Ecological studies 17. Springer, Berlin Heidelberg New York, pp 174–180

Kallio P, Mäkinen Y (1978) Vascular flora of Inari Lapland. 4. Betulaceae. Rep Kevo Subarct Res Stn 14:38–63

Kalliola R (1941) Tunturimittari (*Oporinia autumnata*) subalpiinisten koivikoiden tuholainen (in Finnish). Luonnon Ystävä 2:53–60

Karlsson PS, Weih M (2001) Soil temperatures near the distribution limit of the mountain birch (*Betula pubescens* ssp. *czerepanovii*): implications for seedling nitrogen economy and survival. Arct Antarct Alpine Res 33:88–92

Karlsson PS, Weih M (2003) Long-term patterns of leaf, shoot and wood production after insect herbivory in the mountain birch. Funct Ecol 17:841–850

Karlsson PS, Olsson L, Hellström K (1996) Trade-offs among investments in different long-shoot functions – variation among mountain birch individuals. J Ecol 84:915–921

Kauppi A, Rinne P, Ferm A (1988) Sprouting ability and significance for coppicing of dormant buds on *Betula pubescens* Ehrh. stumps. Scand J For Res 3:343–353

Kullman L (1981) Some aspects of the ecology of the Scandinavian subalpine birch forest belt. Wahlenbergia 7:99–112

Kullman L (1991) Structural change in a subalpine birch woodland in north Sweden during the past century. J Biogeogr 18:53–62

Kullman L (1993) Tree-limit dynamics of *Betula pubescens* ssp. *tortuosa* relation to climate variability: evidence from central Sweden. J Veg Sci 4:765–772

Kullman L (2002) Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. J Ecol 90:68–77

Lehtonen J (1987) Recovery and development of birch forests damaged by *Epirrita autumnata* in Utsjoki area, north Finland. Rep Kevo Subarct Res Stn 20:35–39

Lehtonen J, Heikkinen RK (1995) On the recovery of mountain birch after *Epirrita* damage in Finnish Lapland, with a particular emphasis on reindeer grazing. Ecoscience 2:349–356

Lehtonen J, Yli-Rekola M (1979) Field and ground layer vegetation in birch forests after *Oporinia* damage. Rep Kevo Subarct Res Stn 15:27–32

MacPhee A, Newton A, MacRae KB (1988) Population studies on the winter moth *Operophtera brumata* (L.) (Lepidoptera:Geometridae) in apple orchards in Nova Scotia. Can Entomol 120:73–83

Maillette L (1982) Structural dynamics of silver birch. I. The fate of buds. J Appl Ecol 19:203–218

Mikola P (1942) Über die Ausschlagbildung bei der Birke und ihre forstliche Bedeutung (in Finnish with German summary). Acta For Fenn 50:1–102

Molau U, Larsson E-L (2000) Seed rain and seed bank along an alpine altitudinal gradient in Swedish Lapland. Can J Bot 78:728–747

Neuvonen S, Ruohomäki K, Bylund H, Kaitaniemi P (2001) Insect herbivores and herbivory effects on mountain birch dynamics. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and biosphere series 27. UNESCO, Paris, and Parthenon, New York, pp 207–222

Nilssen A, Tenow O (1990) Diapause, embryo growth and supercooling capacity of *Epirrita autumnata* eggs from northern Fennoscandia. Entomol Exp Appl 57:39–55

Oksanen L, Oksanen T (1992) Long-term microtine dynamics in north Fennoscandia tundra: the vole cycle and the lemming chaos. Ecography 15:226–236

Oksanen L, Moen J, Helle T (1995) Timber line patterns in northernmost Fennoscandia. Relative importance of climate and grazing. Acta Bot Fenn 153:93–105

Palm T (1959) Folgewirkungen der Verheerung von *Oporinia autumnata* Bkh im Abiskotal i. J. 1954–1956. Eine koleopterologische Untersuchung während der Sommer 1958 und 1959 (in Swedish with German summary). Entomol Tidskr 80:120–136

Remmert H (1991) The mosaic-cycle concept of ecosystems – an overview. In: Remmert H (ed) The mosaic-cycle concept of ecology. Ecological studies 85. Springer, Berlin Heidelberg New York, pp 1–21

Ruohomäki K, Virtanen T, Kaitaniemi P, Tammaru T (1997) Old mountain birches at high altitudes are prone to outbreaks of *Epirrita autumnata* (Lepidoptera: Geometridae). Popul Ecol 26:1096–1104

Ruohomäki K, Tanhuanpää M, Ayres MP, Kaitaniemi P, Tammaru T, Haukioja E (2000) Causes of cyclicity of *Epirrita autumnata* (Lepidoptera, Geometridae): grandiose theory and tedious practice. Popul Ecol 42:211–223

Sandberg G (1963) Växtvärlden i Abisko nationalpark. In: Curry-Lindahl K (ed) Natur i Lappland (in Swedish). Bokförlaget Svensk Natur, Uppsala, pp 885–909

Sandberg G (1965) Abisko national park. National Parks of Sweden Series. Rabén und Sjögren, Stockholm

Schneider JS (1902) Om udsigterne for skovens gjenreisning paa kysterne af Tromsø stift (in Norwegian). Naturen 2:53–61

Skre O, Baxter R, Crawford RMM, Callaghan TV, Fedorkov A (2002) How will the tundra–taiga interface respond to climate change? Ambio Spec Rep 12:37–46

Solheim PT (1976) 80 % av bjørkeskogen i Pasvik drept av bjørkemåler (in Norwegian). Statsskog (Oslo) 1:28

Sonesson M, Hoogesteger J (1983) Recent tree-line dynamics (*Betula pubescens* Ehrh. ssp. tortuosa [Ledeb.] Nyman) in northern Sweden. Nordicana (Québec) 47:47–54

Tenow O (1956) Fjällbjörkmätarens härjningar i abiskodalen sommaren 1955 (in Swedish). Sverig Nat 6:165–173, 184–187

Tenow O (1972) The outbreaks of *Oporinia autumnata* Bkh. and *Operophthera* spp. (Lep., Geometridae) in the Scandinavian mountain chain and northern Finland 1862–1968. Zool Bidr Upps Suppl 2:107 pp

Tenow O (1975) Topographical dependence of an outbreak of *Oporinia autumnata* Bkh. (Lep., Geometridae) in a mountain birch forest in northern Sweden. Zoon 3:85–110

Tenow O (1983) Topoclimatic limitations to the outbreaks of *Epirrita* (= *Oporinia*) *autumnata* (Bkh.) (Lepidoptera: Geometridae) near the forest limit of mountain birch in Fennoscandia. Nordicana (Québec) 47:159–164

Tenow O (1996) Hazards to a mountain birch forest – Abisko in perspective. Ecol Bull 45:104–114

Tenow O, Bylund H (1989) A survey of winter cold in the mountain birch/*Epirrita autumnata* system. Mem Soc Fauna Flora Fenn 65:67–72

Tenow O, Bylund H (2000) Recovery of a *Betula pubescens* forest in northern Sweden after severe defoliation by *Epirrita autumnata*. J Veg Sci 11:855–862

Tenow O, Holmgren B (1987) Low winter temperatures and an outbreak of *Epirrita autumnata* along a valley of Finnmarksvidda, the "cold pole" of northern Fennoscandia. In: Alexandersson H, Holmgren B (eds) Climatological extremes in the mountains, physical backgrounds, geomorphological and ecological consequences. UNGI rapport 65. Department of Physical Geography, Uppsala University, pp 203–216

Tenow O, Nilssen A (1990) Egg cold hardiness and topoclimatic limitations to outbreaks of *Epirrita autumnata* in northern Fennoscandia. J Appl Ecol 27:723–734

Tenow O, Nilssen AC, Holmgren B, Elverum F (1999) An insect (*Argyresthia retinella*, Lep., Yponomeutidae) outbreak in northern birch forests, released by climatic changes? J Appl Ecol 36:111–122

Tenow O, Bylund H, Holmgren B (2001) Impact on mountain birch forests in the past and the future of outbreaks of two geometrid insects. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and biosphere series 27. UNESCO, Paris, and Parthenon, New York, pp 223–239

Tenow O, Bylund H, Karlsson PS, Hoogesteger J (2004) Rejuvenation of a mountain birch forest by an *Epirrita autumnata* (Lepidoptera: Geometridae) outbreak. Acta Oecol 25:43–52

Thórsson ÆT, Salmela E, Anamthawat-Jónsson K (2001) Morphological, cytological, and molecular evidence of introgressive hybridisation in birch. J Hered 92:404–408

Tømmervik H, Høgda KA, Karlsen SR (2001) Using remote sensing to detect caterpillar outbreaks in mountain birch forests – a new approach. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and biosphere series 27. UNESCO, Paris, and Parthenon, New York, pp 241–249

Uffeln K (1916) Beobachtungen über die Eiablage von *Cheimatobia brumata* L. und andere Herbstspanner. Z Wiss Insektenbiol 12:169–175

Vaarama A, Valanne T (1973) On the taxonomy, biology and origin of *Betula tortuosa* Ledeb. Rep Kevo Subarct Res Stn 10:70–84

Verwijst T (1988) Environmental correlates of multiple-stem formation in *Betula pubescens* ssp. *tortuosa*. Vegetatio 76:29–36

Virtanen T, Neuvonen S, Nikula A (1998) Modelling topoclimatic patterns of egg mortality of *Epirrita autumnata* (Lep., Geometridae) with geographical information system: predictions for current climate and warmer climate scenarios. J Appl Ecol 35:311–322

Vorren K-D, Engelskjøn T (1974) Planteliv. In: Vorren K-D (ed) Øvre Dividal. Norges Nasjonalparker 7 (in Norwegian). Luther Forlag, Oslo, pp 38–69

Weih M, Karlsson PS (1999) The nitrogen economy of mountain birch seedlings: implications for winter survival. J Ecol 87:211–219

13 Synthesis Section 2: Herbivory in Northern Birch Forests

S. Neuvonen and F.E. Wielgolaski

13.1 Introduction

Climate, humans, reindeer, and autumnal moth have been identified as the factors most permanently affecting the development and structure of subarctic birch forests in northern Europe (Holtmeier 2002; see also Oksanen et al. 1995). The chapters in this section focus on the dynamics and effects of both mammalian and insect herbivores in these ecosystems, and the interactions with climate and man are also dealt with.

Chapter 9 summarises our current knowledge of the regional history of insect outbreaks on birch in northernmost Fennoscandia, and goes on to recent developments in the detection, monitoring and modelling of the outbreak risks in different landscapes along a climatic (oceanity–continentality) gradient. Chapter 10 focuses on the interactions between domestic herbivores (mainly sheep) and birch along the climatic gradient from Greenland, via Iceland and Scotland, to northern Finland. Chapter 11 reviews trends and patterns in reindeer densities, and the effects of reindeer grazing on different pasture components, with a discussion of historical and economical changes, which have affected herding practices in Finland, Sweden and Norway. Chapter 12 starts with case studies on the long-term impact of herbivores in different kinds of birch forests, and presents a conceptual model which highlights the role of both insect and ungulate herbivory in the regeneration cycles of mono- and polycormic mountain birch forests.

The scale and extent of studies in this section range from interactions between individual birch seedlings and sheep (Chap. 10), via stand level comparisons (Chap. 11: impacts of reindeer grazing; Chap. 12: forest recovery after insect outbreaks), to regional comparisons (Chap. 9: risks of insect outbreaks; Chap. 12: herbivory impacts in different kinds of birch forests). The time spans involved vary also considerably: from one single to a few years (Chap. 10: clipping experiments to simulate sheep browsing) to centuries (Chap. 12: birch forest regeneration cycles).

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

Climate is important for the birch–herbivore interactions in several ways: climatic factors have a strong influence on the risk and intensity of insect outbreaks, to the habitat selection and performance of ungulate grazers, and to the fate of individual birches and forest stands after damage. Climate also has indirect impacts, namely by affecting human activities (both quantity and quality) in these areas. The impact of human activities on the mountain birch ecosystem depends on the density of the human population, on how large the proportion of income comes from other sources (e.g. sea, freshwater habitats, coniferous forests), and on the specific kinds of activities in the birch forests (logging, sheep and/or reindeer husbandry, tourism). There are large regional differences in these respects, and these differences have a long history (cf. Chap. 19, and chapters in Sect. 3. this Vol.).

This chapter summarises herbivory in northern birch forests in relation to sustainable use under changing anthropogenic and environmental, i.e. climatic conditions. Regional differences (Table 13.1) are highlighted throughout, in addition to the interactions between insects, ungulates and humans.

Table 13.1. Regional differences in the occurrence of different herbivore species in birch forests along the oceanity–continentality gradient from SW Greenland to N Finland. Note that the possibilities for human "control" of herbivore species decrease from the top to the bottom. *C* Vole densities show often (3–)4–5 year cycles in these areas; +, ++, +++ little, middle, great importance

	Greenland	Iceland	Scotland	N Norway	N Sweden	N Finland
Domestic and semi-domestic herbivores						
Sheep	+++	+++	+++	++	(+)	(+)
Reindeer	+			+++	+++	+++
Other mammalian herbivores						
Moose				++	++	+
Red deer			++			
Roe deer			++			
Hare	++[a]		++[b,c]	++[c]	++[c]	++[c]
Voles			+	++C	++C	++C
Insect herbivores						
Operophtera spp. + Other geometrids[d]	++	++	++	+++		
Epirrita autumnata				+++	+++	+++

[a] Arctic hare

[b] Brown hare

[c] Mountain hare

[d] See Koponen (1983)

13.2 Insect Outbreaks

Insects such as autumnal and winter moths rarely cause defoliation in southern latitudes. However, in some areas along the Scandinavian mountain chain, they show rather regular cycles or outbreaks of varying amplitude (Tenow 1972). Normally, the insects defoliate birches only partially and the trees can recover. However, sometimes the insect outbreaks cause widespread death of trees. For example, in northernmost Finland, *E. autumnata* defoliated birches in hundreds of square kilometres in the mid-1960s, and it was predicted that large areas will become treeless "tundra" (Kallio and Lehtonen 1973). Indeed, the recovery of the birch forest has been very slow, large areas remaining virtually treeless even about four decades after the damage (Sihvo 2002). This has clearly decreased the possibilities for traditional livelihoods (reindeer herding, grouse hunting) in the area.

Understanding the regional variations in winter minimum temperatures (associated with topographies and oceanity–continentality) enhances our possibilities to predict the risk of insect outbreaks in different parts of northern Europe under changing climate (Chaps. 9, 12; see also Neuvonen et al. 1999). Cold winter temperatures (below ca.–35 °C) kill the eggs of autumnal moths and restrict outbreaks both geographically and locally (Tenow 1975; Tenow and Nilssen 1990). For example, in the more continental areas in eastern Fennoscandia, the outbreaks do not occur at regular intervals and forests on valley floors are often saved due to temperature inversion. Higher winter temperatures will increase the frequency of insect outbreaks in the continental areas, but may not affect the defoliation risks in the oceanic areas where the minimum temperatures are already far above the critical temperature. On the other hand, increasing summer temperatures may restrict the area and intensity of outbreaks due to increased pressure from the natural enemies of defoliating insects (Virtanen and Neuvonen 1999). Warmer summers will also enhance the capacity of birches to recover from damage.

In addition to summer temperatures, the recovery potential and regeneration rate of mountain birch forests depend on birch growth form (mono- vs. polycormic) and on grazing pressure (Chap. 12). Monocormic trees are characteristic for the fresh heath- and nutrient-rich meadow birch forests on the western, oceanic side of the Scandes, while polycormic (multi-stemmed) birches dominate the heath forests on the eastern side of the mountain chain. In polycormic mountain birch forests, heavy insect defoliation triggers regeneration by sprouting, while the regeneration in monocormic birch forests is mainly by seeds. Under favourable conditions, regeneration by sprouting can be relatively rapid, but even then it takes several decades. Regeneration from seeds is very slow, often hazardous, and may easily fail.

13.3 Mammalian Herbivores

Chapters 10–12 focus mainly on reindeer and sheep, but to complement this we should not forget the role of other mammals (Table 13.1). Starting from the smaller end of the size range, cyclic density fluctuations of voles are very prominent in the northern birch forests (e.g. Henttonen and Wallgren 2001). The peak vole densities (normally at 4–5 year intervals) are often high enough to cause strong impacts on vegetation, including tree seedlings (Hörnfeldt 1978; Hansson 1988; Oksanen and Oksanen 1992). In addition, through their effects on the predator community, vole fluctuations can indirectly affect the alternative prey species like grouse (Hörnfeldt 1978; Angelstam et al. 1985). Other common mammalian herbivores that can sometimes cause considerable browsing pressure in birch forests are mountain hare, red and roe deer (Scotland), and moose (Fennoscandia; see also Chap. 5).

The number of reindeer in northern Fennoscandia has undergone large spatial and temporal variation, but the numbers peaked in all countries quite synchronously in the 1980s (Chap. 11). Many recent studies indicate that especially many winter pastures have been overgrazed (Tømmervik et al. 2004; cf. Chap. 17). However, some pastures are in relatively good condition. The variability in the numbers of reindeer and pasture conditions results from the variability in productivity and climatic conditions as well as different herding systems practised in different parts of northern Fennoscandia as summarised in Chapter 19 (see also Chaps. 16, 23).

A review of experimental studies of reindeer grazing shows a consistent reduction in lichen coverage in grazed areas (Chap. 11, cf. Chaps. 4, 17). However, other pasture components exhibited highly variable responses to reindeer grazing. Birch tended to have lower coverage or biomass, lower height and lower seedling density in grazed areas. Grasses tended to have a higher coverage and biomass in grazed areas.

In the more oceanic parts of northern Europe, sheep often browse in mountain birch forests. In Iceland, heavy grazing by sheep has even resulted in widespread erosion, not just vegetation damage, which can be very difficult to redress (Aradottir and Arnalds 2001). Although sheep grazing has a strong influence on birch forests also in Greenland, Scotland, and northern Norway, we still do not completely understand the impacts of sheep browsing on birch under different conditions. Co-ordinated research efforts are needed to reveal whether birch responses to ungulate herbivory vary along climatic (e.g. oceanity–continentality) gradients.

To study the effects of severity and timing of simulated sheep/reindeer browsing on birch saplings, parallel experiments were done in the HIBECO project in Finland, Scotland and Iceland (Chap. 10). The results from these experiments can be summarised by saying that simulated browsing in winter was least detrimental to the regrowth of birch, spring/early summer effects were mostly intermediate, whilst late summer browsing had the most detrimental effects on sapling growth. Increasing severity of simulated browsing had increasingly detrimental effects on growth, particularly in late summer. Results from Greenland showed that year-round grazing by sheep was clearly much more damaging than summer grazing only. The treatment effects in the experimental study were consistent across different countries, i.e. birch sapling responses to simulated browsing did not vary much along the oceanity–continentality gradient.

In general, birch is very resilient against browsing and is capable of partial compensatory growth (Chap. 10). However, if browsing continues over more than a few years, it is likely that the negative effects will become increasingly apparent if the resources of the saplings are being repeatedly depleted. The same is also true with birch defoliation by insects (Kaitaniemi et al. 1999), although high defoliation levels seldom last longer than 2–3 years (Tenow 1972).

The lack of seedlings as well as foliage in the lower parts of trees is characteristic for birch forests browsed by sheep or reindeer during summer (Helle 2001). Intensive grazing by ungulates can halt the regeneration cycle of monocormic birch forests at an open woodland or a meadow stage (Chap. 12). Furthermore, the regeneration of polycormic mountain birch forests can be seriously slowed down or even prevented by heavy reindeer grazing (Lehtonen and Heikkinen 1995).

13.4 Implications for Sustainable Management

Defoliation of mountain birch forests by insects is obviously the most important disturbance factor in these northern ecosystems, and a combination of insect defoliation and heavy grazing by (semi)domestic animals may become problematic. Consequently, the natural hazards caused by defoliating insects as well as the additional difficulties for forest regeneration due to mammalian herbivory have to be taken into account when sustainable use of the area is planned. The risk of insect outbreaks may increase in certain (continental) areas if minimum winter temperatures become higher.

Sustainable sheep and reindeer herding in mountain birch forests requires lower animal densities than those currently found in many areas. For the recovery of lichen pastures and birch seedling establishment, lower animal densities are essential, whereas for an established mountain birch forest moderate grazing may improve growth. The effects of reindeer grazing are site-specific. Consequently, management decisions should be based on detailed information on local conditions (soil fertility, climatic conditions, history of insect outbreaks, vegetation type, pasture rotation etc.). Most sensitive areas (establishing young birch stands), especially those where the risk of insect outbreaks is high, should be protected from heavy grazing.

The problems associated with sheep and reindeer grazing in northern birch forests have already been recognised for a considerable time. The activities to improve grazing management in birch forest areas in different countries are reviewed in Chapter 11. These range from suggestions to fully protect birch woodlands from grazing sufficiently often and widespread re-introduction of birch in Iceland, to management agreements to reduce numbers of both sheep and deer in certain areas in Scotland. Attempts to facilitate birch forest recovery from the large-scale insect damage in Finnish Lapland have been initiated as a co-operative effort by state authorities and local stakeholders. Local participation in planning sustainable management in the northern birch forest ecosystem should be encouraged because, as detailed above and in Chapters 9–12, regional and local differences in environmental conditions are pronounced (see also Chap. 22). Local knowledge will also be needed, e.g. in selecting the optimal timing of activities like the planting of birch seedlings in areas where animal (insects, voles, hare) populations naturally show large density fluctuations (Table 13.1).

References

Angelstam P, Lindström E, Widén P (1985) Synchronous short-term population fluctuations of some birds and mammals in Fennoscandia – occurrence and distribution. Holarctic Ecol 8:285–298

Aradottir AL, Arnalds O (2001) Ecosystem degradation and restoration of birch woodlands in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch forest ecosystems. Man and biosphere series 27. UNESCO, Paris and Parthenon, New York, pp 293–306

Hansson L (1988) Grazing impact by small rodents in a steep cyclicity gradient. Oikos 51:31–42

Helle T (2001) Mountain birch forests and reindeer husbandry. In: Wielgolaski FE (ed) Nordic mountain birch forest ecosystems. Man and biosphere series 27. UNESCO, Paris and Parthenon, New York, pp 279–291

Henttonen H, Wallgren H (2001) Rodent dynamics and communities in the birch forest zone of northern Fennoscandia. In: Wielgolaski FE (ed) Nordic mountain birch forest ecosystems. Man and biosphere series 27. UNESCO, Paris and Parthenon, New York, pp 261–278

Holtmeier F-K (2002) Tiere in der Landschaft. Einfluss und ökologische Bedeutung. Ulmer, Stuttgart, 367 pp

Hörnfeldt B (1978) Synchronous population fluctuations in voles, small game, owls, and tularemia in northern Sweden. Oecologia (Berl) 32:141–152

Kaitaniemi P, Neuvonen S, Nyyssönen T (1999) Effects of cumulative defoliations on growth, reproduction, and insect resistance in the mountain birch. Ecology 80:524–532

Kallio P, Lehtonen J (1973) Birch forest damage caused by *Oporinia autumnata* (Bkh.) (Lep., Geometridae) in 1965–66 in Utsjoki, N Finland. Rep Kevo Subarctic Res Stn 10:55–69

Koponen S (1983) Phytophagous insects of birch foliage in northernmost woodlands of Europe and eastern North America. Nordicana 47:165–176

Lehtonen J, Heikkinen RK (1995) On the recovery of mountain birch after *Epirrita* damage in Finnish Lapland, with a particular emphasis on reindeer grazing. Ecoscience 2:349–356

Neuvonen S, Niemelä P, Virtanen T (1999) Climatic change and insect outbreaks in boreal forests: the role of winter temperatures. Ecol Bull 47:63–67

Oksanen L, Oksanen T (1992) Long-term microtine dynamics in north Fennoscandia tundra: the vole cycle and the lemming chaos. Ecography 15:226–236

Oksanen L, Moen J, Helle T (1995) Timber line patterns in northernmost Fennoscandia. Relative importance of climate and grazing. Acta Bot Fenn 153:93–105

Sihvo J (2002) Ylä-Lapin luonnonhoitoalueen ja Urho Kekkosen kansallispuiston luontokartoitus. Loppuraportti osa 2: Ylä-Lapin luontotyypit (in Finnish). Metsähallituksen luonnonsuojelujulkaisuja Sarja A No 137:1–170+3 maps

Tenow O (1972) The outbreaks of *Oporinia autumnata* Bkh. and *Operophthera* spp. (Lep., Geometridae) in the Scandinavian mountain chain and northern Finland 1862–1968. Zool Bidr Uppsala Suppl 2:1–107

Tenow O (1975) Topographical dependence of an outbreak of *Oporinia autumnata* Bkh. (Lep., Geometridae) in a mountain birch forest in northern Sweden. Zoon 3:85–110

Tenow O, Nilssen A (1990) Egg cold hardiness and topoclimatic limitations to outbreaks of *Epirrita autumnata* in northern Fennoscandia. J Appl Ecol 27:723–734

Tømmervik H, Johansen B, Tombre I, Thannheiser D, Högda KA, Gaare E, Wielgolaski FE (2004) Vegetation changes in the Nordic mountain birch forest: the influence of grazing and climate change. Arct Antarct Alpine Res 36:322–331

Virtanen T, Neuvonen S (1999) Performance of moth larvae on birch in relation to altitude, climate, host quality and parasitoids. Oecologia 120:92–101

Section 3

Human Impact

14 Rates and Processes of Natural Regeneration in Disturbed Habitats

B.C. Forbes, A. Tolvanen, K. Laine and F.E. Wielgolaski

14.1 Introduction

Surface disturbance from recreational hiking and camping has been reported from a number of ecosystems in various parts of the world, and is also common in the Nordic mountain birch ecosystem. This will be of increasing importance in the future as the use of these birch forests and adjacent alpine-arctic areas for tourism purposes has grown dramatically in recent decades (Bäck et al. 1989; Ilyina and Mieczkowski 1992; Sippola et al. 1995; Gnieser 2000; Godde et al. 2000; Prokosch 2001; Monz 2002; Chaps. 15 and 24). Recovery after surface disturbances in high altitude and latitude mountain birch systems is normally slow due to the generally low temperatures, short growing seasons, and the often nutrient-poor soil (see below). In dense mountain birch forests also low light intensity may reduce the recovery rate.

Very few controlled field experiments have been carried out on the ecological effect of surface disturbance within the northern mountain birch forest itself. However, it may be postulated that the effects will be of the same order as in similar vegetation types above and north of the present tree line. The Nordic mountain birch forest is also expected to expand in response to climate change to higher elevation and further north, as stressed in several chapters in this volume (see, e.g., Chaps. 1 and 21). This means that the plant field and bottom layers of today's low alpine-arctic ecosystems in the future may be within the subalpine–subarctic mountain birch forests in Fennoscandia.

Ecological impacts of surface disturbance, natural or man-made, are many and include, among others, reductions in the diversity and abundance of plant species (Liddle 1997), growth forms (Bayfield et al. 1981; Forbes 1992b) and soil fauna (Bayfield 1979a; Kevan et al. 1995), changes in vegetation cover, structure and productivity (Cole and Bayfield 1993; Forbes et al. 2001), floristic convergence among sites and colonization by non-native species (Schreiner 1982; Gorchakovskii 1985; Gorchakovskii and Korobeinikova

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

1997), and increases in soil erosion (Bryan 1977; Liddle 1997; Grieve 2000), soil compaction and concomitant reductions in porosity and infiltration (Monti and Mackintosh 1979; Gellatly et al. 1986a).

Most studies of foot and vehicle traffic have been short term and few controlled experimental studies of recreation impact have, as mentioned, been conducted in the Nordic mountain birch forest and even beyond the northern tree line (Liddle 1997; Yorks et al. 1997). More common have been experiments with camping and associated pedestrian trampling in these and related ecosystems (Bayfield 1979a,b; Cole and Bayfield 1993; Cole 1995a,b; Marion and Cole 1996; Arnesen and Moen 1997), as well as more retrospective descriptions of 'recovery' from sites of long-term impact where levels of use can only be estimated (Hoogesteger 1984; Gellatly et al. 1986a,b; Forbes 1996; Gorchakovskii and Korobeinikova 1997; Wielgolaski 1998).

Findings from around the circumpolar North are seen as generally comparable, in contrast to studies from the southern hemisphere, because of the many floristic and environmental similarities in arctic and subarctic regions (Gnieser 2000) like the Nordic mountain birch forest. However, blanket generalizations on the ostensible 'fragility' of tundra plants have been criticized and dictate that a more local approach be taken (Oksanen and Virtanen 1995). Furthermore, experimental methods have varied widely, making comparisons difficult even among closely situated sites with similar soils and vegetation types (e.g. Emanuelsson 1984; Tolvanen et al. 2001). In response, there has been an effort to institute common sampling protocols (Cole and Bayfield 1993) and this has been adopted in more recent studies in Nordic mountain birch forests (Finland; Tolvanen et al. 2001) and more arctic areas (Gnieser 2000; Monz 2002). Yet, of the few genuine experimental studies conducted in subarctic or arctic ecosystems (Emanuelsson 1984; Gnieser 2000; Monz 2002), monitoring for periods longer than a few years remains uncommon (see, however, Tarnocai and Veldhuis 1998). This chapter will focus on rates and processes of natural regeneration in habitats disturbed by recreation impacts, with special emphasis on the subarctic mountain birch forest and neighbouring zones in Fennoscandia.

Dahl (1975) observed that the erosional features resulting from human trampling were relatively unimportant in Fennoscandia as a whole. Similarly, Emanuelsson (1984) felt that, except in areas in the immediate vicinity of roads, trails and tourist infrastructure, trampling effects on vegetation in the Swedish mountains seemed to be of "limited importance". In fact, damages tend to be concentrated at and above the tree line – where tourist tracks are typically channelled along the most favourable ascension routes from forested areas to higher ground for unobstructed views of the surrounding lowlands. A recent survey in Swedish Lapland has found that over 30 % of multi-day hikers reported "significant wear" on the natural surroundings and 50 % of all respondents agreed partly or completely that tourists' wear on vegetation in the mountain "is a problem" (cf. Chap. 15). Similar patterns of impact and erosion are perhaps more noticeable in Finland, which is much less mountainous than either Norway or Sweden and thus contains limited high-elevation terrain. As a result, most of the sizable and accessible mountains in northern Finland ('vaara' in Finnish) are characterized by tourist developments entailing extensive networks of summer hiking and winter skiing and snowmobiling trails (Helle and Särkelä 1993; Ukkola 1995; see also Chap. 15).

14.2 Processes of Regeneration

Disturbance in the Nordic mountain birch forest close to the tree line is important because it produces patches of partially or totally denuded ground that permit propagule establishment but may also open affected areas to erosion (Forbes et al. 2001). In a review of some 400 literature sources from different biomes around the world, Yorks et al. (1997) reported that the greatest general population- and community-level losses in vegetation tend to take place after the first few passes by people or vehicles. This is consistent with research by Cole and Bayfield (1993) who, after repeated experiments in temperate and alpine ecosystems, found no clear evidence to suggest any difference between the effects of trampling all at once and spreading the trampling out over a few months.

Similarly, Tolvanen et al. (2001) report that the negative impact of hiking on subarctic vegetation in both the Nordic mountain birch forest understorey and in nearby dwarf shrub heath is logarithmic: a reduction in species cover and density occurs quickly and at relatively low trampling intensities, after which the measurable level of change is considerably reduced. A visible trail is formed even after 10–25 passes, and a threshold level of a significant cover reduction seems to occur between 75 and 200 passes (Tolvanen et al. 2001). One hundred and fifty passes on flat terrain causes the same relative decrease in vegetation cover as 25 passes on steep slopes, i.e. the impact of trampling is six times greater on the slopes than on flat terrain (Törn et al., unpubl.). It should be noted that, in practice, the numbers of hikers on nature trails in summer are considerably greater than in the experiments, where the maximum number of passes has been 500 (Tolvanen et al. 2001) or 900 (Törn et al., unpubl.). To be realistic, we have to talk about hundreds or thousands of users during a single summer period.

Forest mosses (e.g. *Pleurozium schreberi*, *Hylocomium splendens*) seem to react more slowly than the other plant life-forms to damage from hiking in summer, although skiing has a negative influence on such mesic vegetation (see Chap. 15), but both their decrease and recovery follow the other functional types. Among mosses, *Dicranum* and *Polytrichum* species are most resistant to trampling. The timing of experimental hiking does not seem to influence the vegetation cover, which decreased similarly independent of whether the hiking treatment was carried out in June, July or August (Törn et al., unpubl.). In an earlier study in northern Sweden, trampling in late summer was found to be more deleterious than early season trampling in meadow vegetation, whereas timing had no influence on the resistance of heath vegetation (Emanuelsson 1984). In the dwarf-shrub-dominated heaths, the seasonal intra-plant translocation of nutrients is apparently not as clear as in the forb-dominated meadows, as dwarf shrubs store a greater amount of their assimilates in their aboveground organs.

In addition to environmental factors, such as low air and soil temperatures, short growing season and often low availability of nutrients near the tree line and above (e.g. Bliss 1962; Billings 1987), regeneration after trampling is constrained by plant characteristics, such as slow growth rates and limited dispersion capabilities through sexual reproduction. Yet, in some cases, disturbance may actually increase plant productivity of graminoids, if not shrubs as well, at least in experimental studies carried out in tundra areas (Chapin and Shaver 1981; Forbes 1992a, 1998), but probably also in similar vegetation types in the Nordic mountain birch forests. Studies have found enhanced productivity to be associated with various substrate changes, such as increases in soil bulk density and decomposition (Gersper and Challinor 1975), radiation absorption and soil temperature (Chapin and Shaver 1981), fluxes of CO_2 to the atmosphere (Zimov et al. 1999), and increase in nutrient availability (Challinor and Gersper 1975; Herbein and Neal 1990).

Plants tolerate disturbances depending on the combined resistance and resilience of each species and the rate of regeneration after disturbance of tundra and Nordic mountain birch understorey plants (Cole 1995a,b; Tolvanen et al. 2001). Many graminoids and deciduous dwarf shrubs have high rates of photosynthesis and growth, and large belowground organs for carbon/nutrient storage (Chapin 1980; Bryant et al. 1983; Karlsson 1985). Such plants normally regenerate well after disturbance and are more competitive than less resilient species, such as cushion plants and evergreen dwarf shrubs (e.g. Chapin 1980).

Recent studies of regeneration by seed in subarctic Fennoscandia provide information relevant to the disturbance and vegetation types discussed here. Welling and Laine (2002) found densities of both seeds and seedlings to be higher in meadow than in heath vegetation at Kilpisjärvi, Finland. In Iceland regeneration of the mountain birch forest by seed is common after soil degradation by sheep grazing (Aradóttir and Arnalds 2001; Magnússon and Magnússon 2001). This was the case in all phases of the 'regeneration pathway' from seed production to standing vegetation. Although seed production, and therefore seed banks, in such habitats can be large, seedling recruitment tends to be negligible in relatively undisturbed vegetation (Molau and Larsson 2000). Rather, studies from different regions and vegetation types across the Arctic indicate that seedling density is generally highest on disturbed ground and is also typical for the Nordic mountain birch forest (see Chaps. 4 and 17; cf. Kinnaird 1974; Aradóttir and Arnalds 2001). This has been shown for both natural and anthropogenic disturbance regimes. While intense local disturbance, such as frost heave, can trigger high rates of germination, mortality can be so great that net recruitment is kept to a minimum (Nielsen 1997). Experimental removal of successive field layers in a more stable understorey vegetation, dominated by *Vaccinium myrtillus* and *V. vitis-idaea*, indicated that relatively strong mechanical disturbance is needed to enhance sexual reproduction (Hautala et al. 2001). Taken together, these findings suggest that the patches of bare ground resulting from heavy trampling in the Nordic mountain birch heath and meadow understorey vegetation may present opportunities for colonization from seed, provided that frost heave, soil compaction, or soil erosion are not too severe.

14.3 Rates of Regeneration

Once disturbed, natural regeneration of even lightly or moderately trampled vegetation and soils can be a very slow process, although this depends in part on factors like substrate slope, temperature, moisture, nutrient status, and the latitude of the site. In a review (Forbes et al. 2001), similarly created high arctic patches were indeed found to return more slowly toward the productivity and physiognomy of their respective control communities than they did in subarctic mountain birch forests and in low arctic regions. On all but the wettest sites, after two or more decades, disturbed patches remained distinct from adjacent undisturbed ground in terms of vegetation composition, cover, and certain edaphic parameters (e.g. soil pH, temperature, thaw depth, etc.). Close to the tree line in Norway tractor tracks more than 50 years old often seem to be less than 5 years old based on their appearance (Wielgolaski 1997).

In the short term, studies in subarctic Fennoscandian mountain birch forest and heaths have reported hiking tracks becoming visible after as little as 25 (Tolvanen et al. 2001) to 70 trampling passes (Gellatly et al. 1986b) in heath vegetation. 'Delayed action' responses in heath and dwarf-shrub communities have been observed by Bayfield (1979b) and Gellatly et al. (1986b), in which plants continued to die for up to 1 year after the initial impact at levels of 70 or more passes. This is similar to the situation observed close to the mountain birch tree line at Kilpisjärvi, Finnish Lapland, where plants of *Empetrum nigrum* continued to die 1 year, and *Betula nana* well into the second year, after one-time experimental trampling treatments (Forbes et al., unpubl.).

At the population level, three groups of plants clearly differed in their response to trampling in the Nordic mountain birch zone study in Finland by Tolvanen et al. (2001). The most tolerant species were *Carex bigelowii* and the group of three forbs in which the population density was the same as in the control even in the most intense trampling treatment. *Vaccinium myrtillus* and *V. vitis-idaea* were intermediate in their tolerance, since old tillers suffered from trampling, but the resilience was high even after 1 year. These species were therefore expected to rapidly achieve full recovery within the trampled area. The most vulnerable species were *Dryas octopetala* (Wielgolaski 1998), *B. nana*, and *E. nigrum*, in which resilience decreased with increasing trampling intensity. Old branches from which branching occurred in *D. octopetala*, *B. nana*, and *E. nigrum* were dramatically damaged, indicating low resistance in these species.

Emanuelsson (1984) reported on natural regeneration after 2 years in similar vegetation types in northern Sweden. Although his sampling protocol makes his results not directly comparable with those from the Cole and Bayfield (1993) experimental method, he observed significant recovery in both *Empetrum* heath and *V. myrtillus* heath. Nonetheless, he estimated that damage from more than 50–150 passes per year, depending on vegetation type, would still be visible after 35–50 years.

Monz (2002) followed regeneration in two vegetation types in experimentally trampled tundra in northern Alaska. Although different from the vegetation types currently under investigation in the Nordic mountain birch forest (Tolvanen et al. 2001; Forbes et al., unpubl.), it is worth noting that he observed a distinct threshold between the low–moderate and high levels of impact. Five hundred passes resulted in an immediate loss of approximately 50 % cover in dwarf shrub tundra dominated by *Dryas octopetala* and 70 % cover loss in cottongrass tundra dominated by *Eriophorum angustifolium*. After 4 years impact was still evident in plots subjected to 200 and 500 passes, but vegetation cover and height had more or less returned to pre-disturbance levels in plots subject to 25 and 75 passes.

Arnesen (1999) experimentally trampled several vegetation types in central Norway, making 300 passes annually over a period of 5 years. In his results from the 'damp heath' vegetation, *V. myrtillus* displayed rather high resistance (sensu Cole and Bayfield 1993) and was able to maintain a relatively stable presence in the paths for the first 4 years, before eventually decreasing to 50 % of its original cover. This appears to be greater resistance than that measured by Tolvanen et al. (2001) and may be related to the relative moisture of the predisturbance habitats, since the *V. myrtillus* heath investigated by the latter occurred on fairly dry, nutrient-poor soils.

There is little published information on rates of regeneration for periods longer than 5 years, at least in Fennoscandia. The literature contains only a couple of studies, and these have necessarily relied on data from uncontrolled trampling plots. Coker et al. (1998) measured resilience over a 22-year period in four montane habitats in central Norway and reported relatively rapid recovery of *Salix herbacea* snowbed and *Vaccinium myrtillus* heath vegetation compared to *Betula nana* and lichen heath. Even a 'low level' of trampling was clearly visible after two decades in the latter two vegetation types. Wielgolaski

(1998) also followed 22 years of natural regeneration in Norwegian arctic-alpine tundra within three vegetation types following 'severe' uncontrolled trampling over a period of 5 years. In the lichen heath, ground cover of all life forms combined remained below 25 % for nearly a decade. It was only after two decades that total cover approached 100 %, with about 85 % of this provided by bryophytes (*Polytrichum* spp.) and lichens (*Cladonia* spp., *Cetraria* spp., and, especially, *Ochrolechia frigida*). Compared to untrampled ground, the vegetation composition still differed significantly even after 22 years. He estimated the 'under-representation' of vascular plants on trampled ground to be more than 50 %.

14.4 Conclusion

In the controlled trampling experiments in the understorey of Nordic mountain birch forests reviewed in this chapter, relatively low levels of trampling were applied compared with the amount of trampling pressure occurring under normal conditions in recreational areas in the mountain birch zone in Fennoscandia (see Chap. 15). Hence, the experiments provide important information primarily on the initial vegetation and soil responses during pedestrian trampling or following the cessation of short-term trampling. In reality, however, hiking trails can be subject to tens of thousands of passes during their lifetime, and the pressure may persist for decades. Long-term observations on the vegetation connected with concrete data on the earlier trampling pressures (by, e.g., visitor counts) are needed in order to provide a more realistic understanding of the regeneration rates occurring under ongoing disturbance.

References

Aradóttir AL, Arnalds O (2001) Ecosystem degradation and restoration of birch woodlands in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris, Parthenon, New York, pp 293–306

Arnesen T (1999) Vegetation dynamics following trampling in grassland and heathland in Sølendet Nature Reserve, a boreal upland area in central Norway. Nord J Bot 19:47–70

Arnesen T, Moen A (1997) Landscape history coming alive: history, management and vegetation of the outlying haymaking lands at Sølendet Nature Reserve in central Norway. In: Cooper A, Power J (eds) Proc 6th IALE Conf on Species Dispersal and Land Use Processes, Coleraine, UK, pp 275–282

Bäck L, Josefsson M, Strömquist L (1989) Land capability, recreational land-use and conservation strategies in a sensitive mountain environment. Uppsala Naturgeogr Inst 73:1–68

Bayfield NG (1979a) Some effects of trampling on *Molophilus ater* (Meigen) (Diptera, Tipulidae). Biol Conserv 16:219–232

Bayfield NG (1979b) Recovery of four montane heath communities on Cairngorm, Scotland, from disturbance by trampling. Biol Conserv 15:165–179

Bayfield NG, Urquhart UH, Cooper SM (1981) Susceptibility of four species of *Cladonia* to disturbance by trampling in the Cairngorm Mountains, Scotland. J Appl Ecol 18:303–310

Billings WD (1987) Constraints to plant growth, reproduction, and establishment in arctic environments. Arct Alpine Res 19:357–365

Bliss LC (1962) Adaptations of arctic and alpine plants to environmental conditions. Arctic 15:117–144

Bryan RB (1977) The influence of soil properties on degradation of mountain hiking trails at Grövelsjön. Geogr Ann 59A:49–65

Bryant JP, Chapin FS III, Klein DR (1983) Carbon/nutrient balance of boreal plants in relation to vertebrate herbivory. Oikos 40:357–368

Challinor JL, Gersper PL (1975) Vehicle perturbation effects upon a tundra soil-plant system. II. Effects on the chemical regime. Soil Sci Soc Am Proc 39:689–705

Chapin FS III (1980) Nutrient allocation and responses to defoliation in tundra plants. Arct Alpine Res 12:553–563

Chapin FS III, Shaver GR (1981) Changes in soil properties and vegetation following disturbance of Alaskan arctic tundra. J Appl Ecol 18:605–617

Coker P, Glaves P, Kent M (1998) Long-term recovery response of montane vegetation subject to recreational trampling. In: Sjögren E, van der Maarel E, Pokarzhevskaya G (eds) Vegetation science in retrospect and perspective (abstracts). Opulus Press, Uppsala, p 65

Cole DN (1995a) Experimental trampling of vegetation. I. Relationship between trampling intensity and vegetation response. J Appl Ecol 32:203–214

Cole DN (1995b) Experimental trampling of vegetation. II. Predictions of resistance and resilience. J Appl Ecol 32:215–224

Cole DN, Bayfield NG (1993) Recreational trampling of vegetation: standard experimental procedures. Biol Conserv 63:209–215

Dahl E (1975) Stability of tundra ecosystems in Fennoscandia. In: Wielgolaski FE (ed) Fennoscandian tundra ecosystems, part 2. Animals and systems analysis. Springer, Berlin Heidelberg New York, pp 231–236

Emanuelsson U (1984) Ecological effects of grazing and trampling on mountain vegetation in northern Sweden. PhD Thesis, Department of Plant Ecology, University of Lund

Forbes BC (1992a) Tundra disturbance studies. I. Long-term effects of vehicles on species richness and biomass. Environ Conserv 19:48–58

Forbes BC (1992b) Tundra disturbance studies. II. Plant growth forms of human-disturbed ground in the Canadian Far North. Musk-ox 39:46–55

Forbes BC (1996) Plant communities of archaeological sites, abandoned dwellings, and trampled tundra in the eastern Canadian Arctic: a multivariate analysis. Arctic 49:141–154

Forbes BC (1998) Cumulative impacts of vehicle traffic on high arctic tundra: soil temperature, plant biomass, species richness and mineral nutrition. Nordicana 57:269–274

Forbes BC, Ebersole JJ, Strandberg B (2001) Anthropogenic disturbance and patch dynamics in circumpolar tundra ecosystems. Conserv Biol 15:954–969

Gellatly AF, Whalley WB, Gordon JE (1986a) Footpath deterioration in the Lyngen Peninsula, north Norway. Mount Res Dev 6:167–176

Gellatly AF, Whalley WB, Gordon JE, Ferguson RI (1986b) An observation on trampling effects in north Norway: thresholds for damage. Norsk Geogr Tidsskr 40:163–168

Gersper PL, Challinor PL (1975) Vehicle perturbation effects upon a tundra soil-plant system. I. Effects on morphological and physical environmental properties of the soils. Soil Sci Soc Am Proc 39:737–744

Gnieser CH (2000) Ecological consequences of recreation on subarctic-alpine tundra: experimental assessment and predictive modeling as planning tools for sustainable visitor management in protected areas. PhD Thesis, University of Calgary, Alberta

Godde PM, Price MF, Zimmerman FM (eds) (2000) Tourism and development in mountain regions. CABI Publishing, Oxon, UK, 352 pp

Gorchakovskii PL (1985) Anthropogenic changes in vegetation: monitoring, evaluation, and prognosis. Soviet J Ecol 15:229–240

Gorchakovskii PL, Korobeinikova VP (1997) Synanthropization of vegetation in the upper belts of the Urals. Russian J Ecol 28:323–329

Grieve IC (2000) Effects of human disturbance and cryoturbation on soil iron and organic matter distributions and on carbon storage at high elevations in the Cairngorm Mountains, Scotland. Geoderma 95:1–14

Hautala H, Tolvanen A, Nuortila C (2001) Regeneration strategies of dominant boreal forest dwarf shrubs in response to selective removal of understorey layers. J Veg Sci 12:503–510

Helle T, Särkelä M (1993) The effects of outdoor recreation on range use by semi-domesticated reindeer. Scand J For Res 8:123–133

Herbein SA, Neal JL (1990) Phosphatase activity in arctic tundra soils disturbed by vehicles. Soil Bio Biochem 22:853–858

Hoogesteger M (1984) The effect of trampling on vegetation at four cottages in Torne Lapland, northern Sweden. Rep Kevo Subarct Res Stn 19:25–34

Ilyina L, Mieczkowski Z (1992) Developing scientific tourism in Russia. Tourism Man 12:327–331

Karlsson S (1985) Patterns of carbon allocation above ground in a deciduous (*Vaccinium uliginosum*) and an evergreen (*Vaccinium vitis-idaea*) dwarf shrub. Physiol Plant 63:1–7

Kevan PG, Forbes BC, Behan-Pelletier V, Kevan S (1995) Vehicle tracks on high arctic tundra: their effects on the soil, vegetation and soil arthropods. J Appl Ecol 32:656–669

Kinnaird JW (1974) Effect of site conditions on the regeneration of birch (*Betula pendula* Roth and *B. pubescens* Ehrh.). J Ecol 62:467–472

Liddle M (1997) Recreation ecology: the ecological impact of outdoor recreation and ecotourism. Chapman and Hall, London

Magnússon SH, Magnússon B (2001) Effect of enhancement of willow (*Salix* spp) on establishment of birch (*Betula pubescens*) on eroded soils in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris, Parthenon, New York, pp 317–329

Marion JL, Cole DN (1996) Spatial and temporal variation in soil and vegetation impacts on campsites. Ecol Appl 6:520–530

Molau U, Larsson E-L (2000) Seed rain and seed bank along alpine altitudinal gradient in Swedish Lapland. Can J Bot 78:728–747

Monti PW, Mackintosh EE (1979) Effect of camping on surface soil properties in the boreal forest region of northwestern Ontario, Canada. Soil Sci Soc Am J 43:1024–1029

Monz C (2002) The response of two arctic tundra plant communities to human trampling disturbance. J Environ Manage 64:207–217

Nielsen AL (1997) Seedling establishment in a frost-disturbed environment. MSc Thesis, University of Copenhagen

Oksanen L, Virtanen R (eds) (1995) Geographical ecology of northernmost Fennoscandia. Acta Bot Fenn 153:1–110

Prokosch P (2001) Tourism: threat or benefit to conservation? In: Kankaanpää P, Huntington H, Baldursson S, Sippola AL, Kaitala S, Zöckler C, Gunn A, Mirutenko M, Prokosch P, Tishkov A (eds) Arctic flora and fauna: status and conservation. Edita, Helsinki, pp 102–103

Schreiner EG (1982) The role of exotic species in plant succession following human disturbance in an alpine area of Olympic National Park, Washington. PhD Thesis, University of Washington, Seattle

Sippola A-L, Alaraudanjoki P, Forbes BC, Hallikainen V (eds) (1995) Northern wilderness areas: ecology, sustainability, values. Arctic Centre Publ 7, University of Lapland, Rovaniemi, pp 1–438

Tarnocai C, Veldhuis H (1998) Soils and trafficability of Pangnirtung Pass, Auyuittuq National Park Reserve. Prepared for Auyuittuq National Park Reserve by the Research Branch (ECORC, BRC), Agriculture and Agri-Food Canada, Ottawa

Tolvanen A, Forbes BC, Rytkönen KE, Laine K (2001) Regeneration of dominant plants after short-term pedestrian trampling in sub-arctic plant communities. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris. Parthenon, New York, pp 359–368

Ukkola R (1995) Trampling tolerance of plants and ground cover in Finnish Lapland, with an example from the Pyhätunturi National Park. Zeszyty Naukowe Uniwersytetu Jagiellonskiego 98:91–110

Welling P, Laine K (2002) Regeneration by seeds in alpine meadow and heath vegetation in sub-arctic Finland. J Veg Sci 13:217–226

Wielgolaski FE (1997) Fennoscandian tundra. In: Wielgolaski FE (ed) Polar and alpine tundra. Elsevier, Amsterdam, pp 23–33

Wielgolaski FE (1998) Twenty-two years of plant recovery after severe trampling by man through five years in three vegetation types at Hardangervidda. NTNU Vitensk Mus Rapp Bot Ser 4:26–29

Yorks TP, West NE, Mueller RJ, Warren SD (1997) Toleration of traffic by vegetation: life form conclusions and summary extracts from a comprehensive database. Environ Manage 21:121–131

Zimov SA, Davidov SP, Zimova GM, Chapin FS III, Chapin MC, Reynolds JR (1999) Contribution of disturbance to increasing seasonal amplitude of atmospheric CO_2. Science 284:1973–1976

15 Recreation at Tree Line and Interactions with Other Land-Use Activities

A. Tolvanen, B. Forbes, S. Wall and Y. Norokorpi

15.1 Introduction

The relatively undeveloped nature of large areas of the Fennoscandian subalpine transition zone from the coniferous timberline to the Nordic mountain birch tree line provides an ideal environment for recreation. The first national parks in Europe were established in Sweden in 1909, in Finland in 1938 but in Norway not until 1962, in order to preserve areas for nature conservation and recreation. In all Fennoscandian countries, large conserved areas are mostly situated in the north and mainly in the mountain birch forest and above, in Norway also in southern mountain districts. In nearly all conserved areas in Finnish Lapland and also in Sweden and Norway, recreation is very important. Recreation is also active around large tourism business areas, such as Saariselkä, Ylläs and Levi in Finland, Sälen, Idre, Vemdalen, Åre, Riksgränsen and Björkliden in Sweden, and Geilo, Hemsedal, above Lillehammer, Trysil, Voss, Oppdal and Björnfjell/Narvik in Norway, all of them mainly in the mountain birch zone. The relative importance of tourism as a source of income is constantly increasing above the coniferous timberline, with a simultaneous relative decrease in traditional sources of livelihood, such as forestry and farming. At present in Finland, the income from tourism exceeds the income from agriculture and forestry in many rural municipalities (Saastamoinen et al. 2000).

Recreation is based on so-called everyone's rights, which are exceptionally wide in Fennoscandia. Free access to and use of both public and private land are allowed, provided no harm is caused to people, animals or vegetation. Traditional outdoor activities, e.g. hiking, skiing and biking, and gathering of berries and mushrooms are allowed for everyone, whereas restrictions are sometimes made regarding, e.g., camping for more than one night in the same place. In national parks, local people are usually allowed to continue hunting and fishing and reindeer herding, but the increase in recreation may in some parks lead to restrictions on the possibilities of continuing these traditional

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

activities. In order to maintain future tourism activities at ecologically, socially and economically sustainable levels, practical measures are needed to determine the appropriate levels of sustainability. To achieve this difficult and complex aim, close cooperation between research, administration, planning and local people is crucial (see Chaps. 23 and 24).

Generally, research on the ecological impacts of recreation in mountain regions started in Fennoscandia during the 1960s (e.g. Wielgolaski 1978), which is considerably later than, e.g. in North America and Great Britain, where vegetation studies were carried out as early as the 1930s (Bates 1935). Most published Finnish studies on ecological impacts of mass recreation have been carried out south of the mountain birch region (e.g. Kellomäki 1973; Nylund et al. 1979; Malmivaara et al. 2002). Hoogesteger, however, investigated the vegetation changes around wilderness huts in Finnish and Swedish Lapland (Hoogesteger 1976, 1984; Hoogesteger and Havas 1976), while Tolvanen et al. (2001) and Forbes et al. (see Chap. 14) have studied the impact of experimental trampling on regeneration at and above the mountain birch belt. In Swedish Lapland, regeneration of subarctic heath vegetation was monitored in the experimental studies of Emanuelsson (1984), while Norwegian studies carried out in the mountain birch tree-line region have investigated the effects of, e.g. expeditions on heath vegetation and soil (Gellatly et al. 1986), experimental or recreational trampling on the recovery of fen, grassland and heath vegetation (Arnesen 1999a,b), and the recovery after 22 years of natural regeneration following trampling within three vegetation types in the low alpine zone (Wielgolaski 1998).

In this chapter, we summarize results on long-term impacts of recreation at coniferous timberline and mountain birch ecosystems, based on case studies carried out mainly in the Pallas-Ounastunturi National Park in Finland and in the Lake Torne area in Sweden during recent years. The common aims of the studies have been to investigate whether recreation is ecologically sustainable in these environments, and the levels of sustainability in such regions. This chapter does not discuss controlled trampling experiments, which are reviewed in Chapter 14. There has been a remarkable amount of research done on recreation near the Finnish coniferous timberline and in mountain birch regions, but most of the studies are unfortunately still unpublished or available only in Finnish. A comparable situation occurs in Sweden. Other objectives of this chapter are to discuss the interaction of recreation and tourism with other land-use activities in coniferous timberline and mountain birch ecosystems, such as nature conservation, forestry and traditional livelihoods, and also to discuss tourism from the viewpoint of sustainability. Although all kinds of outdoor activities in nature are classed as recreation, most recreation studies have concentrated on the traditional nature-oriented recreation activities, i.e. hiking, cross-country skiing and camping. These activities are most popular in nature conservation areas, where a significant amount of the research is being carried out. Nevertheless, the increasing off-road traffic by four-wheel motor vehicles and snowmobiles has had more impact on the environment than any other tourist activity, particularly near tourist resorts. In this chapter, tourism is understood as both outdoor recreational activities and infrastructures to support recreation, plus the cultural and economical impacts by visitors.

15.2 Case Study Areas

Studies have been carried out at the coniferous timberline and in subalpine mountain birch environments in the Finnish Pallas-Ounastunturi National Park and Urho Kekkonen National Park (UKK park) since the early 1990s. In Sweden, studies have been carried out near the northern boreal-subalpine tree line with Nordic mountain birch and some pine trees in the Lake Torne area since the early 1980s, and recently in the south Jämtland mountain area (e.g. Bäck and Bäck 1986; Bäck and Jonasson 1998; Wall 2001; Vuorio 2003).

Pallas-Ounastunturi National Park belongs to the northern boreal zone, and the vegetation of the lower areas of the park is coniferous heath vegetation. A 100-km-long subalpine fell range runs through the middle of the park. The location of the timberline is approximately at 420 m a.s.l., ranging from 470 to 380 m at the western and eastern slope, respectively (Seppänen and Norokorpi 1998). On the southern fells of the national park, the timberline is formed by Norway spruce without a pure mountain birch belt above it. The timberline ecosystem is influenced by crown snow load, i.e. accumulation of frost, ice and snow on tree crowns, to such an extent that the severity of snow damage makes the growth and regeneration of birch impossible at higher altitudes than spruce (Norokorpi 1994). In the northern parts of the park, there is a mountain birch belt above the coniferous forests formed by Scots pine because of more barren and drier soils. The so-called crown snow-load limit is located at higher altitudes and it is not a minimum factor to tree growth there (Norokorpi 1994).

Pallas-Ounastunturi National Park was established in 1938 in order to protect locally valuable forests and mires and local cultural habitats, such as meadows and reindeer pastures near the tree line. The number of annual visitors is approximately 100,000; the number has increased 2.5- to 4-fold over the past 20 years (Penttilä et al. 1998). It is estimated that 40 % of tourists visit during the summer and 60 % in winter (Tervo 2003). The park has 200 km of official skiing trails and 120 km of hiking trails (Penttilä et al. 1998). Hence, recreation has an impact on the environment throughout the year, but in the form of different activities, which are often concentrated within different areas. The annual maximum visitor number of certain wilderness huts and camping sites approaches 5000, and during the nights of peak periods there may be 150 people in a camping area (Trast 2001). Due to the heavy impact of people in Pallas-Ounastunturi National Park, the park is classified as class IV according to the Protected Area Management Categories of the IUCN (Penttilä et al. 1998). Class IV indicates a protected area managed mainly for landscape conservation through management intervention. Usually, national parks with a lower human impact are classified as class II, which indicates a protected area managed mainly for ecosystem protection and recreation.

UKK park is located in eastern Lapland in the upper coniferous and Nordic mountain birch ecosystems, with a special creeping birch form (var. *appressa*) in the north of the park (cf. Chap. 7). The park became a popular tourist area in the 1950s (Rautio et al. 2001), and the number of visitors has grown dramatically with the development of the tourist resort of Saariselkä. The estimated number of annual visitors is in the order of 150,000 people, but it varies depending on the calculation method and whether day hikers or wilderness hikers are counted (Rautio et al. 2001).

The Lake Torne area is located in the northern part of the Swedish Lapland Mountains, in the county of Norrbotten. Parts of the Lake Torne area are designated by UNESCO as a Biosphere Reserve, within the research programme Man and Biosphere (MAB). The Lake Torne Area Biosphere Reserve consists of mountains, valleys, meadows and lakes. The landscapes are characterized by subalpine mountain birch forest and alpine and subalpine heaths (Wall 2001). Several protected areas are included in the Biosphere Reserve; two national parks and three nature reserves. The national park of Abisko was established in 1909, and Vadvetjåkka National Park in the far north-west of the study area was set up in 1920 (Bäck 2002).

Tourism in the Swedish Lapland Mountains began in the 1880s, although at a modest scale. Development of the communication network, maps and travel books, and improvements in the infrastructure in the region (establishments for overnight stops, trail markings) were important factors behind the expansion of tourism at the end of the 19th century and beginning of the 20th century in the mountains of northern Sweden, but also in many mountain and mountain birch regions of southern Norway. The Swedish Touring Club (Svenska Turistföreningen, STF) was of great importance for the development of mountain tourism (Bäck and Bäck 1986). Tourism increased by 10 % per year in the mountains of Norrbotten from the 1950s to the mid-1970s. After road construction was completed in 1984 between Kiruna and Narvik, for a long distance through the Nordic mountain birch forest, the number of tourists staying in hotels increased to more than 166,000 (Bäck and Bäck 1986). However, the number of tourists started to decrease in the 1990s due to the reduced attractiveness to adventurous tourists (Bäck 2002). Several tourism establishments are presently located on the south shore of Lake Torne (Fig. 15.1), three of which have ski lifts for downhill skiing. In the area there are marked trails for winter and summer activities. A visitor survey of hotel visitors in 2002 reveals that 50 % of the tourists come during summer (June to

Fig. 15.1. As a result of improved communication near the mountain birch line, huge hotels are often built, e.g. in northern Sweden (*left*), while private cottages are more common at the tree line in Norway (*right*). (Photo: L. Bäck)

September) and 45 % during winter (January to May), while the period from October to December is quiet in the area. About 75 % of winter visitors go downhill skiing, while the most popular summer activity is one-day hiking (65 %), followed by several-day hikes (20 %; Wall, unpubl.).

15.3 Monitoring Studies on the Impact of Recreation on the Environment in Lapland

In the national park Pallas-Ounastunturi, large-scale surveys have been repeatedly carried out since 1991 to investigate the condition of hiking trails (Norokorpi, unpubl.). Besides the surveys, trail investigations have been made in order to estimate the suitability of contrasting vegetation types, soil characteristics, slope, altitude and aspect for hiking (Koivula 2000), to estimate the suitability of different vegetation types to hiking in summer and cross-country skiing (Tervo 2003), or the impacts of camping and wilderness huts on vegetation (Trast 2001). Besides Pallas-Ounastunturi National Park, surveys to map the condition of hiking trails and surroundings of wilderness huts have been carried out in the Finnish UKK park (Rautio et al. 2001). In Sweden, one study has been carried out recently in the southern part of the Swedish mountain range, in the county of Härjedalen, in 1999. The purpose of the study was to investigate whether the area had been exposed to a non-sustainable wear of vegetation or erosion, and to identify which parts were the most exposed (van den Brink and Vikman 2000).

Ecological changes are inevitable even after slight and short-term trampling, particularly at higher elevation with a long recovery period (see Chap. 14). The direct impact of recreation is always negative: the value of the environment decreases as a consequence of wear and decreased visual quality. The long-term physical influence of hiking and skiing is to compact the soil and reduce the thickness of the soil humus layer, especially on slopes (Tervo 2003). On old trails there is no vegetation, and the main issue is to keep their spatial dimensions under control, i.e. prevent their further expansion. Changes in the condition of tracks may be rapid, for instance, the width and depth of a hiking trail have been found to increase at maximum 70 cm in width and 1.5 cm in depth, averages being 3.1 and 0.15 cm, respectively, during a 3-month summer period with less than 1000 hikers on dry fell heaths of Pallastunturi (Koivula 2000). In the Finnish UKK park with over 150,000 day hikers per year, the width of trails varies between 1.4 and 3.6 m, the widest points being 8 m, which can also be seen from distances of many kilometers (Rautio et al. 2001). The deepest points can be over 30 cm, which may be partially a consequence of water erosion (Rautio et al. 2001).

Slopes are most sensitive to wear due to the combined influence of trampling and water erosion, the latter occurring especially during the snowmelt period. This can easily be seen on trails on slopes, e.g. at the mountain birch tree line in Kilpisjärvi, northwestern Finland. In areas of high wear, complete closure of the trail or artificial structures, e.g. stairs, duckboards, or cover by gravel or pavement, are probably the only methods to protect the environment from further wear.

The impacts of summer hiking and cross-country skiing on soil and vegetation differ considerably (Tervo 2003). The direct influence of skiing on vegetation is not as great as that of hiking, which may considerably increase the cover of graminoids at the coniferous timberline and in mountain birch environments. On the other hand, the influence of skiing is spread over a wider area compared with hiking, since the skiing trails are broader and, especially near tourist resorts, maintained by machines, which press and compact the snow and delay the timing of snowmelt. The tolerance of vegetation to hiking and skiing is opposite between the dry and mesic vegetation types: hiking in summer has been observed to reduce the plant cover most in the dry *Calluna*-dominated vegetation, whereas skiing has a negative impact on the mesic *Hylocomium–Myrtillus*-dominated vegetation found, e.g. in the bottom layer of the mountain birch forests. The negative impact is based on a decreased cover of the dominant deciduous dwarf shrubs, which are found to be replaced by evergreen species (Tervo 2003). The great width of the modified area and the time to recover during summer may create opportunities for light-favouring species, such as lichens and evergreen plants, to increase on skiing trails (Tervo 2003). Lichens have sometimes been observed to be more common also on old trails than on new trails. Early recolonization of lichens may occur from lichen fragments surviving after large plants have been destroyed. These fragments can lead to rapid recolonization even in the middle of a track (Emanuelsson 1984), unless reindeer graze them.

Camping has an even greater impact on vegetation than hiking in mountain birch ecosystems. According to Cole (1988), the impact of one camping occasion is comparable with 75–150 passes by trampling. At Pallas-Ounastunturi National Park, the altered vegetation area around the wilderness huts varies between 50 and 1450 m^2 (Trast 2001), whereas at UKK park, with a higher recreation pressure, the area varies between 170 and 1530 m^2 (Rautio et al. 2001). At UKK park, the altered vegetation area around wilderness huts increased 2.5–19-fold in 1999 (Rautio et al. 2001) compared with the measurements carried out at the same sites 25 years earlier (Hoogesteger 1976). During this time period, summer visitor numbers increased five-fold at some huts, from 1000–5000 people (Rautio et al. 2001). Around old huts the cover of graminoids is higher compared with the surroundings of the new huts (Trast 2001), similar to the trend that has been observed between old and new hiking and skiing trails (Tervo 2003). The intensity of the disturbance apparently influences the difference in vegetation between old and new hiking trails and wilderness huts. Recreation pressure on old trails and huts has increased slowly, which has allowed time for secondary grass-dominated vegetation to form in the area. At new sites, e.g. in the mountain birch forests, where trampling has been intense since the beginning, secondary vegetation has not been able to colonize the area (see also Hoogesteger 1984).

Recreation in the form of large-scale infrastructures especially at or close to tourist resorts has remarkable environmental effects. Bäck and Jonasson (1998) have been working on long-term environmental impact assessment before, during and after road construction in the mountain birch and upper pine forests between Kiruna and Narvik in Swedish Lapland. The secondary aspects of the road construction, such as buildings, ski lifts, connection roads, and a golf course have intensive effects on the environment. Construction of road further increases the wear on nature, for example by increased use of areas close to the roads, increased use of motor vehicles over the terrain, and by new establishments for recreation. Also littering increases near resting and parking places (Bäck and Jonasson 1998).

15.4 Interaction of Recreation with Other Land-Use Activities

Nature-based tourism is a fast-growing business and will be an increasingly important source of income in mountain birch ecosystems of northern Fennoscandia. It interacts both with older, established land-use and with nature conservation activities, since a considerable amount of recreation is concentrated in conservation areas and valuable habitats. Recreation can cause conflicts between different stakeholders due to too similar interests (e.g. recreation and conservation) or contrasting interests (e.g. recreation vs. forestry).

15.4.1 Recreation vs. Nature Conservation

Those working in nature-based tourism and those working in conservation share the same interests. According to Budowski (1976), there are three categories in the relationship between tourism and nature conservation. Conflict arises when tourism has negative impacts on nature or when the two co-exist but have little contact with each other. An extreme example is the construction of downhill ski slopes in scenic parts of mountain birch forests, often combined with building of hotels, parking lots and ski lifts (see Chap. 24, Fig. 24.3). In this context, the direct negative impacts of recreation on nature are emphasised, such as vegetation and soil changes, erosion, disturbance to animals, and reduced visual and aesthetic values. On the other hand, conflict arises from a situation where tourism is a victim of an already deteriorated environment (e.g. by industry, mining, forestry) that would otherwise attract people.

Another category in Budowski's (1976) classification is co-existence, which indicates that under certain circumstances tourism and conservation may co-exist. Co-existence can be attained by dividing areas into different use in time or space. For example, in Pallas-Ounastunturi National Park in Finnish Lapland, zoning has been used to limit access to the most sensitive sites, e.g. according to special vegetation types near the tree line. Hiking in restricted

Fig. 15.2. Tourist trail in the Nordic mountain birch forest with duckboards to protect the vegetation and the people against getting wet. Note that preferably the protection of the trail should have been wider to be more effective. (Photo: L. Bäck)

zones is forbidden during summer. In the less restricted wilderness zones and the least restricted basic zones, hiking and skiing are allowed. However, official trails are only located in the basic zones, which concentrates most recreational use within these least sensitive habitats.

The third category, symbiosis, occurs when appreciation of nature and conservation increases as a consequence of tourism (Budowski 1976). Tourism is often argued to be the last possibility for protection of nature (Saastamoinen et al. 2000). A consequence may be the establishment of new conservation areas in order to increase tourism and recreation. This leads to a complex situation, since recreation has a negative impact on the nature in the new conservation areas. Special steps may then be taken to lead the majority of tourists along marked trails, maybe with a cover of, e.g. gravel or duckboards in particularly sensitive vegetation types, such as in some mountain birch forest areas (Fig. 15.2).

15.4.2 Recreation vs. Forestry

The relationship between recreation and forestry reflects the relationship between nature conservation and forestry, as recreational activities are supported by conservation. It is estimated that nature conservation reduces clear-cutting opportunities on average by 10 %, the percentage being even higher (18 %) in state-owned forests in Finland (Mäki et al. 1997). Hence the establishment of protected areas may violate the local economy by cutting off the productivity of forestry, a situation that has occurred, e.g. in Finnish Lapland (Saastamoinen et al. 2000). Although this is most important in coniferous forests, it also concerns the use of mountain birch forests, particularly for fuel wood. Tourism increases the need for fuel wood, but cutting may be restricted (but cf. Chap. 16). Compensations have been addressed to smooth the losses of local economies, but they have not always been well targeted to actual losers, i.e. people working in forestry (Saastamoinen et al. 2000). A significant problem may arise when an individual forest owner loses direct income from selling wood, while the benefits may go to the development of infrastructure for tourism and hence to people who are not forest owners.

15.4.3 Recreation vs. Traditional Livelihoods

Reindeer herding is an essential human activity in recreational areas and national parks of coniferous timberline and mountain birch environments in northern Fennoscandia. For example, approximately 10,000 reindeer belonging to three reindeer herding associations graze in the area of Pallas-Ounastunturi National Park. The park region is important for the reindeer due to the availability of epiphytic lichens (*Alectoria* spp. and *Bryoria* spp.) during winter, during the calving period in spring, and as an escape from mosquitoes during summer, when the reindeer are willing to climb to the high fells (Rauhala 1994; Warenberg et al. 1997). The reindeer herders have the right to use snowmobiles and four-wheel motor vehicles in conjunction with their work. In very sensitive fell areas, the combined influence of reindeer and recreation may be the strongest factor influencing the vegetation. Mobilized and more intensive reindeer herding has increased the numbers of reindeer (cf. Chaps. 11 and 19), which has had a negative impact on the cover of lichens, especially fruticose forms, and even the regeneration of mountain birch (Lehtonen and Heikkinen 1995; Chaps. 4 and 17), besides the direct negative influence on the terrain by the vehicles. According to Emanuelsson (1984), there are similarities in the influence of trampling and grazing on vegetation in mountain birch forests and heaths, as vegetation resistance to both these disturbances varies depending on the vegetation type, and fast-growing rapidly recovering plants, such as graminoids and deciduous dwarf shrubs, are favoured. If the pressure of both activities is too high at a site, no vegetation can survive in the area. In these areas, lichen are usually missing and the mineral soil is exposed. Areas with most erosion are windy sites used by reindeer and/or for recreation (van den Brink and Vikman 2000).

Since recreation and reindeer herding compete for the same resources, a conflict easily arises. The reindeer herders worry about tourism in the mountain birch region and above (cf. Chap. 23), especially snowmobiling activities during spring and disturbance by hikers in summer (Wall 2001). Disturbance has increased the avoidance of tourist resorts by reindeer, leading to the increased use and overgrazing of remaining undisturbed grazing grounds (Nellemann et al. 2000; Vistnes and Nellemann 2001). Also visitors with dogs disturb reindeer, especially if they hike off the marked trails (Helle and Särkelä 1993; Rauhala 1994; Autto 1999). Reindeer cows and reindeer calves during the calving season are easily disturbed, whereas reindeer bulls are less likely to avoid areas with a high human impact (Wolfe et al. 2000). Disturbance may increase the time spent being vigilant and standing, mostly at the expense of time spent resting and foraging (Duchesne et al. 2000).

The creation of recreational opportunities for tourists may simultaneously result in restricted access for local people, who may feel that they have preferential rights to their home district and its natural resources (cf. Chaps. 18 and 23). In nature conservation areas, fishing and hunting are usually allowed for local people, but only by permission. Even though the permission is easy to get, the need to apply is considered frustrating (Mäkinen 1998; Autto 1999). According to interviews with local people near Pallas-Ounastunturi National Park, the rights of the visitors should be restricted, e.g. regarding hiking outside the marked trails, whereas the rights of the locals should be increased, e.g. regarding fishing, hunting and the use of four-wheel motor vehicles (Rauhala 1994; Mäkinen 1998).

15.4.4 Recreation vs. Recreation

Even different forms of recreation interact with each other. Differing opinions or even conflicts may arise, for example between people interested in traditional non-motorized activities such as hiking and cross-country skiing and those interested in modern activities such as downhill skiing and snowmobiling (Kajala 2001), which have increased strongly in the Nordic mountain birch forests over the last decades (cf. Chap. 24). Since the quietness of nature is one of the most important attractions for tourists (Järviluoma 2001), motorized vehicles, crowded trails and bad behaviour, i.e. actions that break the quietness, may cause conflicts between tourists. For example, cross-country skiers experience disturbance by snowmobiles not only on shared tracks but also on tracks where snowmobile use is restricted. The primary cause of the disturbance is noise and exhaust from snowmobiles (Lindberg et al. 2001). Opinions on the wear of nature may also differ among recreation groups. According to a survey carried out in 2002 in the mountain birch region of Lake Torne in Swedish Lapland, more than 30 % of 1-day cross-country skiers and several-day hikers thought that there is a significant wear on nature, while the corresponding value is only 10 % among downhill skiers and several-day cross-country skiers and 22 % for 1-day hikers. Regarding wear on vegetation in the area by tourists, half of the respondents agreed partly or completely on the problem (Wall, unpubl.). To reduce interaction and conflicts between recreation activities, these activities can and often should be separated in time and space. Conflicts may also be reduced by education and participatory planning, where the opinions of different stakeholders are considered.

15.5 Sustainable Tourism

The concept of sustainable tourism is the key to seeking a more productive and harmonious relationship between the environment, visitors and the mountain birch host community. Sustainable tourism can be understood in three basic dimensions: ecological, socio-cultural and economic sustainability (cf. other chapters, this Vol.; Saarinen 1998). Ecological sustainability is concerned with ecological changes caused by recreation and their acceptability over the long term. Socio-cultural and economic sustainability refer to cultural or economical changes, respectively, and their long-term acceptability (Saarinen 1998).

The concept of carrying capacity is crucial with regard to sustainable recreation and it should be included even at the planning stage for the use of a specific area. In biology, carrying capacity has been used in models to determine the maximum population size that can be supported by a given environment (e.g. Lotka-Volterra –model on competition), while in recreation, carrying capacity is defined as the number of visitors that an area can sustain without degrading natural resources and visitor experiences (O'Reilly 1986; McCool 1994). In practice, the ecological carrying capacity can be defined as the maximum amount of recreation before biodiversity and biological functions are endangered, and, consequently, management or restoration of the environment is needed. From the social and ecological perspectives, carrying capacity in the Nordic mountain birch zone indicates that social culture and lifestyle in the zone remain, and that regional and local economical needs are fulfilled.

Carrying capacity is usually not a direct objective measurement, but it can be defined as the "limits of acceptable changes", denoted as LAC (Saarinen 1998). It is evident that some changes occur in every ecosystem due to human activities. In the mountain birch environments, long-term changes can be caused even by slight recreation pressure. The increasing use of motorized vehicles is in places exceeding the ecological carrying capacity due to destruction of vegetation and ground and disturbance to animals. Considering LAC, the focus is on the degree of change that is acceptable in a specific area (Hendee et al. 1990; McCool 1994). LAC is a planning procedure designed to identify preferred social and environmental conditions in advance and to develop management techniques to achieve and protect those conditions (Wight 1998). Hence the purpose is to prevent conflicts caused by recreation, conservation and social interests. However, like every method, LAC has its weaknesses. It is a subjective method and depends on people's interests and values. For example, whether environmental, social or economical aspects are prioritized in the development of a specific area influences the acceptability of the changes occurring in nature. Therefore, valid indicators, measures, standards and participatory management planning are needed for making decisions (see chapters of Section 4).

References

Arnesen T (1999a) Vegetation dynamics following trampling in grassland and heathland in Sølendet Nature Reserve, a boreal upland area in central Norway. Nord J Bot 19:47–69

Arnesen T (1999b) Vegetation dynamics following trampling in rich fen at Sølendet, central Norway; a 15 year study of recovery. Nord J Bot 19:313–327

Autto J (1999) Luonnonsuojelualueen paikallinen merkitys. Esimerkkinä Pallas-Ounastunturin kansallispuisto (in Finnish). MSc Thesis, University of Lapland

Bäck L (1996) Saami and Scandinavians. Natural resource competition in the Swedish reindeer herding region. In: Wheelersburg R (ed) Northern peoples southern states. CERUM, University of Umeå, pp 183–208

Bäck L (2002) Friluftslivet i norra Lapplandsfjällen (in Swedish). In: Bäck L, Christiansson C (eds) Bergen i fokus, Ymer 2002. Svenska Sällskapet för Antropologi och Geografi, Stockholm, pp 152–167

Bäck L, Bäck E (1986) Effekterna av ett vägbygge – väg 98 mellan Kiruna och Riksgränsen. En studie av friluftslivet i Norrbottenfjällen 1979–1985 (in Swedish). Acta Univ Upsaliensis, C 52

Bäck L, Jonasson C (1998) Miljökonsekvensutvärderingar kring väg E 10 mellan Kiruna och Riksgränsen (in Swedish). Forskningsrapport, 109. Kulturgeografiska Institutionen, Uppsala University

Bates G (1935) The vegetation of footpaths, sidewalks, cart-tracks and gateways. J Ecol 23:470–487

Budowski G (1976) Tourism and environmental conservation: conflict, coexistence, or symbiosis? Environ Conserv 3:27–31

Cole DN (1988) Disturbance and recovery of trampled Montana grassland and forests in Montana. Research Paper INT 389. USDA Forestry Service, Ogden

Cole DN, Landers P (1996) Threats to wilderness ecosystems: impact and research needs. Ecol Appl 6:143–148

Duchesne M, Cote SD, Barrette C (2000) Responses of woodland caribou to winter ecotourism in the Charlevoix biosphere reserve, Canada. Biol Conserv 96:311–317

Emanuelsson U (1984) Ecological effects of grazing and trampling on mountain vegetation in northern Sweden. PhD Thesis, Department of Plant Ecology, University of Lund

Gellatly AF, Whalley WB, Gordon JE (1986) Footpath deterioration in the Lyngen Peninsula, north Norway. Mount Res Dev 6:167–176

Helle T, Särkelä M (1993) The effects of outdoor recreation on range use by semi-domesticated reindeer. Scand J For Res 8:123–133

Hendee JC, Stankey GH, Lucas RC (1990) Wilderness management. North American Press, Golden, Colorado

Holmström H (1970) Eräiden Etelä-Suomen vapaa-aika-alueiden kasvillisuuden kulutuskestävyyden tutkimus (in Finnish). Uudenmaan Seutukaavaliitot, Helsinki

Hoogesteger M (1976) Kasvillisuuden muuttuminen Koilliskairan autiotupien ympärillä. [Changes in vegetation around the wilderness huts in Koilliskaira.] Silva Fenn 10:40–53

Hoogesteger M (1984) The effect of trampling on vegetation at four cottages in Torne Lapland, northern Sweden. Rep Kevo Subarct Res Stn 19:25–34

Hoogesteger M, Havas P (1976) Luonnon kulutuskestävyydestä ja virkistyskäytön kanavoinnista Pohjois-Suomen suunnitelluissa kansallispuistoissa (in Finnish). Terra 88:31–34

Järviluoma J (2001) Luonnon merkitys matkailun vetovoimatekijänä: esimerkkinä Levin, Pallaksen, Pyhän ja Luoston matkailukeskukset. [Nature as a tourist attraction attribute: case studies on four tourist centres in Finnish Lapland.] Finn For Res Inst Res Pap 796:51–76

Kajala L (2001) Virkistyskäytön ristiriidat erämaisilla alueilla (in Finnish). Finn For Res Inst Res Pap 800:155–160

Kellomäki S (1973) Ground-cover response to trampling in a spruce stand of *Myrtillus* type. Silva Fenn 7:96–113

Koivula T (2000) Retkeilyreittien kuluminen ja kestävä matkailu Pallastuntureilla. MSc Thesis, Department of Geography, University of Oulu

Lehtonen J, Heikkinen RK (1995) On the recovery of mountain birch after *Epirrita* damage in Finnish Lapland, with a particular emphasis on reindeer grazing. Ecoscience 2:349–356

Lindberg K, Denstadli JM, Fredman P, Heldt T, Vuorio T (2001) Skiers and snowmobilers in södra Jämtlandsfjällen. Are there recreation conflicts? Working Paper 12. European Tourism Research Institute (ETOUR), Karlskrona

Mäki P, Linden M, Uusivuori J (1997) Metsien suojelu ja puuston käyttörajoitukset ja niiden vaikutukset puumarkkinoilla. Pellervon taloudellinen tutkimuslaitos (in Finnish). Raportteja Ja Artikkeleita 152:1–66

Mäkinen M (1998) Kerässiepin kylän Pallas-Ounastunturin kansallispuistoon liittyvät kehitysnäkymät ja tulevaisuuden mahdollisuudet. [Possibilities for future and development views on Pallas-Ounastunturi National Park by inhabitants of Kerässieppi village.] Thesis, Rovaniemi College of Forestry, 42 pp

Malmivaara M, Lofstrom I, Vanha-Majamaa I (2002) Anthropogenic effects on understorey vegetation in *Myrtillus* type urban forests in southern Finland. Silva Fenn 36:367–381

McCool S (1994) Planning for sustainable nature dependent tourism development: the limits of acceptable change system. Tour Recr Res 19:51–55

Nellemann C, Jordhoy P, Stoen OG, Strand O (2000) Cumulative impacts of tourist resorts on wild reindeer (*Rangifer tarandus tarandus*) during winter. Arctic 53:9–17

Norokorpi Y (1994) Havumetsänrajan sijainnin määräytyminen Suomessa. In: Tasanen T, Varmola M, Niemi M (eds) Metsänraja tutkimuksen kohteena. Finn For Res Inst Res Pap 539:7–15

Nylund M, Nylund L, Kellomäki S, Haapanen A (1979) Deterioration of forest ground vegetation and decrease of radial growth of trees on camping sites. Silva Fenn 13:343–356

O'Reilly AM (1986) Tourism carrying capacity – concept and issues. Tour Manage 7:254–258

Penttilä T, Piri E, Vuopio M (eds) (1998) Pallas-Ounastunturin kansallispuisto: hoito- ja käyttösuunnitelma 1998–2017. [Management plan of Pallas-Ounastunturi National Park for the period 1998–2017.] Finn For Res Inst Res Pap 716:1–108

Rauhala E (1994) Pallas-Ounastunturin kansallispuiston vaikutuksia paikalliselinkeinoihin (in Finnish). Thesis, Rovaniemi College of Forestry, 22 pp

Rautio J, Helenius M, Saarinen J (2001) Urho Kekkosen kansallispuiston kuluneisuus: luontomatkailun ympäristövaikutusten seuranta ja mittaaminen. [Measuring the impacts of nature based tourism in Urho Kekkonen National Park in Finnish Lapland – methods and problems.] Finn For Res Inst Res Pap 796:111–124

Saarinen J (1998) Kestävyys, kantokyky ja matkailun kehittyminen: näkökulmia kestävän matkailun problematiikkaan. [Abstract: sustainability, carrying capacity and the development of tourism: the problems of sustainable tourism.] Finn For Res Inst Res Pap 671:15–31

Saastamoinen O, Loven L, Sievänen T (2000) Nature-based tourism in forested north-Europe – case of Finland. Finn For Res Inst Res Pap 792:7–17

Seppänen T, Norokorpi Y (1998) The location of the coniferous timberline in the Pallas-Ounastunturi National Park. In: Tasanen T (ed) Research and management of the northern timberline region. Finn For Res Inst Res Pap 677:67–73

Tervo R (2003) Kasvillisuuden kuluminen vaellus- ja hiihtoreiteillä Pallas-Ounastunturin kansallispuistossa (in Finnish). MSc Thesis, Faculty of Forestry, University of Joensuu, 51 pp

Tolvanen A, Forbes B, Rytkönen K, Laine K (2001) Regeneration of dominant plants after short-term pedestrian trampling in sub-arctic plant communities. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris, and Parthenon, New York, pp 361–370

Trast P (2001) Leiripaikkojen kunto- ja laatuluokitus Pallas-Ounastunturin kansallispuistossa (in Finnish). Thesis, Rovaniemi Polytechnic, 58 pp van den Brink P, Vikman P-Å (2000) Vegetationsförändringar på fjällen i västra Härjedalen, Fältinventering (in Swedish). Rapport 3. Fjällforskningsinstitutet, Mitthögskolan, Sweden

Vistnes I, Nellemann C (2001) Avoidance of cabins, roads, and power lines by reindeer during calving. J Wildl Manage 65:915–925

Vuorio T (2003) Information on recreation and tourism in spatial planning in the Swedish mountains – methods and need for knowledge. Department of Spatial Planning, Blekinge Institute of Technology, Lic Diss Ser 3, and European Tourism Research Institute (ETOUR), Karlskrona, V 12

Wall S (2001) En studie om hållbar utveckling i Torneträskområdet. Arbetsrapport 432 (in Swedish). Kulturgeografiska Institutionen, Uppsala University

Warenberg K, Danell Ö, Gaare E, Nieminen M (1997) Porolaidunten kasvillisuus. Werner Söderström Osakeyhtiö, Helsinki

Wielgolaski FE (1978) High mountain resources and their use or conservation in north Europe. In: IUCN (ed) The use of high mountains of the world. Department of Lands Survey, Tussock Grasslands and Mountain Lands Institute, Wellington, New Zealand, pp 83–97

Wielgolaski FE (1998) Twenty-two years of plant recovery after severe trampling by man through five years in three vegetation types at Hardangervidda. NTNU Vitensk Mus Rapp Bot Ser 4:26–29

Wight P (1998) Tools for sustainable analyses in planning and managing tourism and recreation in the destination. In: Hall CM, Lew AA (eds) Sustainable tourism: a geographical perspective. Longman, New York, pp 75–91

Wolfe SS, Griffith B, Gray-Wolfe CA (2000) Response of reindeer and caribou to human activities. Polar Res 19:63–73

16 Economic Limits and Possibilities for Sustainable Utilization of Northern Birch Forests

B. Solberg, H. Tømmervik, D. Thannheiser and S. Neuvonen

16.1 Introduction

The birch ecosystems have been vital for human survival in northern Europe since the first humans entered these areas, and the ecosystems have over time been rather strongly exposed to multiple use through human occupancy as well as other related activities.

The main purpose of the HIBECO (Human Interactions with the mountain Birch ECOsystem) project has been to provide greater knowledge of the human impacts on the northern birch forest ecosystems and natural conditions, and the future sustainability of these ecosystems (see Preface). As such, economic issues will have to play an important role, and the main objective of this chapter is to analyse the economic possibilities and limits for sustainable utilization of these ecosystems. This is done by, first, focusing on some theoretical issues which are essential prerequisites to clarify in such types of analyses, and, second, providing empirical results from the study areas included in the project.

The concept of "economic limits" in this chapter is related to two principal factors: supply (i.e. limits related to the supply of services and goods from the birch ecosystems considered) and demand (i.e. limits to the demand of goods and services these ecosystems provide).

16.2 Some Theoretical Aspects

An analysis of economic limits and potential for sustainable utilization of northern birch ecosystems has to include at least the following elements:
- Goals – what are the goals for the utilization?
- What is meant by "sustainable utilization"?
- Which utilization alternatives exist?

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

- How to select the best utilization alternatives (or management alternatives).
- How to assure that the best alternatives are realized.

These aspects are discussed in more detail in the following text.

16.2.1 Goals

The goal for the utilization of birch ecosystems is probably one of the most important factors when discussing their sustainability. In general, one would aim at the utilization (or management) that gives the highest welfare. However, welfare is a rather wide and imprecise concept, and it has to be operationalized. Usually, such operationalizations reflect factors that are important in the overall development objectives for the geographical areas involved, and as such the factors are political as they are based on political goals and decisions. Fortunately, in the HIBECO project application, we have defined (and received acceptance for) the following five criteria to use as welfare criteria in the context of birch ecosystem utilization:

C1: Contribution to local, regional and national income and employment
C2: Contribution to local/regional cultural values
C3: Contribution to ecological authenticity
C4: Degree of sustainability based on criteria C1–C3
C5: Ease of implementation

The main economic aspects are covered by C1 as contributions to local, regional and national income and employment. Income is here divided into (1) private income to the forest owners and others utilizing the birch ecosystem for income activities; (2) regional income to the rural areas (measured as contribution to net and gross national product); and (3) national income (measured as contribution to the net and gross national product). Net product is salary plus profit, and gross product is net product plus capital depreciation. Contribution to employment is measured at local, regional and national levels.

16.2.2 Sustainable Utilization

The concept “sustainable” is not unproblematic. However, in this project, we could, as a first step, limit it to mean that none of the criteria C1, C2 and C3 would give declining values over time (i.e. they will be constant or increasing over time).

16.2.3 Identify Utilization Alternatives

The number of possible utilization (or management) alternatives for the birch ecosystems considered are in principle unlimited. However, for practical reasons, we have to limit them to a number that is possible to handle within the analysis framework. Let us assume that we agree on *n* alternatives, A_1, A_2, ..., A_n, which are sufficient to span realistically the possibility set. Each of the alternatives has different use of resources (labour, energy, machinery, ecosystem functions) and gives different benefits over time. Then, for each of the alternatives, one has to identify their use of resources and impacts on the criteria C1–C4 defined above. This implies that one has to quantify these factors in physical and economic terms. The factors not quantifiable have to be described verbally.

The number *n* will differ from case to case, but the minimum number would in practise be three, covering the following cases:

U0: The present utilization (management) of the birch ecosystem

U+: A more intensive utilization than U0 (i.e. more harvesting of birch, more grazing, more tourism)

U–: A less intensive utilization than U0.

However, it is feasible to assume that different "sectors" will change in different directions. We can denote e.g. (F+, R–, T0) as one alternative with increased forestry (F+), decreased reindeer grazing (R–) and with no changes in tourism (T0). Considering only these three sectors and the possible directions of change would give 3 × 3=9 different utilization alternatives. Furthermore, one should consider not only the directions of change but also their relative magnitudes. Finally, the sustainability of different utilization alternatives depends on local conditions, which vary considerably in different parts of northern Fennoscandia.

16.2.4 Select the Best Utilization (Management) Alternative

If possible, one should try to identify the best management alternative. In practise, however, because of uncertainties involved in quantifying and describing the use of resources and benefits created, it may be more realistic to try to exclude the alternatives which are clearly inferior, thus identifying those alternatives that are among the best.

16.2.5 Implementation of the Best Alternatives

After having agreed upon which alternative (or set of alternatives) is best, one has to analyse how to implement this alternative in practise. This is by no means self-evident, and at least two aspects have to be considered: (1) clarify which control variables are available, and (2) discuss what policy means (or combinations of policy means) are most suitable for influencing the control variables.

By control variables we mean here variables that can be influenced by policy instruments, and in our case they include:

- Birch harvest level, size of harvest plots, distance between harvest plots, time between fellings, type of thinnings done (dimensions of extracted trees relative to dimension of remaining trees)
- Reindeer/sheep population density, age/sex distribution of herds, seasonal movement of herds over time and space
- Use of terrain motor vehicles
- Road density
- Tourist visits
- Tourist "bed" capacity (hotels, cottages).

Regarding policy instruments (to be used to influence the control variables), we have three main types: (1) economic instruments (subsidies, fees, taxes), (2) laws and regulations, and (3) information and education. To decide the best use of these instruments is far from easy and straightforward. It should be noted that the implementation aspect has not been a task in the HIBECO project, but see Chapters 20–24.

16.3 Empirical Results

16.3.1 Birch Area and Productivity

One important economic supply factor, which may limit the resource utilization, is the physical state of the ecosystem – in particular the stock sizes and rate of changes over time. This is discussed in more detail in this chapter under the various project areas. However, one should note that only a small part of the livelihoods/income in these areas is nowadays based on the birch ecosystem as such. The main sectors using the ecosystem productivity are reindeer husbandry (see Chaps. 11 and 19) and energy (fuelwood, Chaps. 18 and 23); even tourism (see Chaps. 15 and 24) is mostly based on "values"/"attractions" largely outside the birch forest (e.g. mountain landscapes, downhill skiing, salmon fishing, history and culture).

16.3.1.1 Máze

Tømmervik et al. (see Chap. 4) report that the area of forest in Máze in the county of Finnmark, northern Norway, has increased from 2400 km^2 in 1961 to more than 3500 km^2 in 2000, and that the total live aboveground biomass of the birch forests has increased in this area, consistent with the increase in the area of birch forests in the same period. The tree biomass (as well as the growing stock) increased by more than 60 % in the period 1961 to 2000, but also the biomass of the shrub and field layer increased significantly. The only reduction was found in the biomass of lichens, which showed a significant reduction (70 %) from 1961 to 2000. It is also reported (op. cit.; cf. Chap. 17) that there has been a significant increase in the *Cornus–Myrtillus* birch forests and the moss-rich *Myrtillus* birch forest from about 200 to nearly 800 km^2, which also represents a significant increase in the total live aboveground biomass. Regarding the change from lichen- and dwarf shrub-dominated forests to more grass- and herb-dominated forests in Máze, Tømmervik et al. op cit. point to the situation that several studies show that lichens, crowberry (*Empetrum hermaphroditum*), bilberry (*Vaccinium myrtillus*) and cowberry (*Vaccinium vitis-idaea*) are declining in the face of competition from wavy hair-grass (*Deschampsia fleuxuosa*) and different forbs, and this is found to be an effect of nitrogen since these species are slow-growing and adapted to nutrient-poor systems.

It is also reported that the trampling and grazing of reindeer in the lichen-dominated birch forests of Máze during the summer season may, in addition to precipitation and nitrogen deposition, be a causal effect of the increase and change in the forest structure, and this is partly an effect of removal of “the barrier” afforded by the thick lichen coverage for the birch seeds to sprout (cf. Chaps. 4 and 17). This has again led to an elevation of the timberline by filling in the gap between the tree line and timberline with forest (Sveinbjörnsson et al. 2002). The co-varying relationships between the number of reindeer in the area and the increase in forbs- and grass-dominated forests within this area was also found to be significant.

The greatest impact on the mountain birch forests is from the gathering of firewood by the local inhabitants and cabin owners (see Chaps. 18, 23, 24). This has a direct impact on the age structure and composition of the plant community. In addition, damage is caused by the use of four wheelers and snowmobiles (cf. Chap. 15) also for the transportation of the harvested wood.

The rural population has the right to cut wood in deciduous forests, here birch forests, on state-owned land, without charge, for domestic use. Cabin owners and dealers, for a fee, can be allotted parcels for cutting. Special rules apply to reindeer Sámi (Statskog 1997a). The wood harvested is used for firewood by private households in Máze or in the nearest towns Alta and Hammerfest, where residents may also, for a fee, receive cutting permits. These households have a very high consumption of firewood because running a weekend cabin, with perhaps a sauna, without electricity requires more firewood than a resident Sámi household. Birch wood [with 2.24 million BTU (British thermal units) per cubic meter of dry wood] has a relatively good heating value, outperforming pine (with 2.19 million BTU), and can, as well, be burned green (Blüthgen 1960; Chap. 18). In addition to firewood, smaller amounts of birch are used by Sámi for the construction of reindeer fences or as material for traditional handicrafts, birch being an easily worked wood.

The preferred wood is from the richer forest types such as the *Myrtillus* and moss-rich *Empetrum* forests; these are plentiful and tree heights and trunk circumferences grow to a suitable size there. The meadow forests also serve as resources, since they are often found in accessible areas near the settlements. Here, the thickest and tallest trees are often spared because they must be split before use as firewood, while this is not necessary with smaller trunks.

In earlier times, horses were used for the transportation to the settlement, and were kept for this reason only. Today, four-wheelers with trailers, tractors or snowmobiles are used. Thus, the local distribution of woodcutting has changed markedly compared to earlier times. Whereas, previously, people were dependent on routes that were well enough developed, including the frozen river in winter, now virtually all parts of the forest are accessible. With modern machinery even steep slopes and moor areas can be overcome. However, for practical reasons, areas are still chosen that are easily accessible within a short time. Depending on the forest type and landscape, these areas are normally no further than 1 km from well-maintained roads, which have increased in more recent times (cf. Chaps. 17, 23, 24). This does not apply to woodcutting that takes place during the migrations of Sámi.

In the birch forest and on the fells, the paths that are used for transport of wood, for leisure activities and for reindeer herding are often particularly damaged through the use of four-wheelers. The vegetation cover often shows great damage and deep ruts from vehicles. When routes become no longer passable because of too intense use, the bad places are merely driven around and new paths made. In this way, especially in moors and at waterways, networks of paths are created; these are often visible from far away.

The state forest on the Finnmarksvidda is administered by the “Statskog”; their local contact people grant permits and decide when and where wood may be cut. Also, they are responsible for enforcing the rules. The state has set aside parcels of land especially for the use of small enterprises and private use, although the apportioning of these is not exclusive and is practically not applied. In 1997 in Máze, 19 permits were issued gratis for private use by the rural population and 10 commercial sales permits with a total volume of 228 m^3. In 2001 in Kautokeino municipality at Finnmarksvidda, 188 people were granted licenses for woodcutting (11 of those commercial) with a total volume of 954 m^3 (Statskog 1997b).

16.3.1.2 Målselv

In Målselv, in the county of Troms, northern Norway, the increase in the forests has not been so large as in Máze (cf. Chap. 17). The total area of forest increased from about 2400 km^2 in 1978 to 2800 km^2 in 1999, and the total "live aboveground biomass" (tree, shrub and field layers) showed an increase in the same period. For the lichen biomass expressed as reindeer fodder units, however, a decrease was reported from 1978 to 1990, with a subsequent increase in the biomass from 1990 to 1999. The number of reindeer supported during the winter period (181 days) showed the same trend (see Chap. 4).

Målselv is the only project area that has some industrial utilization of the birch in addition to fuelwood consumption, and the utilization pattern there follows rather closely the average for Troms. The productive forest in Troms in 1992/1993 had an annual yield of about 432,000 m^3 for birch, 58,000 m^3 for pine and 28,000 m^3 for spruce. The birch utilization differs from year to year, but on average during the last 10 years the following annual utilization seems to be a reasonable estimate:

• Industrial use of birch (for particleboard production)	40,000 m^3
• Birch for fuelwood	110,000 m^3
• Pine	15,000 m^3

In addition, birch is used for handicraft and furniture production, but the quantity is rather small – most likely less than 0.5 % of the annual harvest. It follows that only about 27 % of the annual yield of birch is utilized.

16.3.1.3 Other Areas

In Ohcejohka/Utsjoki, Inari and Enontekiö in northern Finland, Tømmervik et al. (see Chap. 4) show that the total volume of wood in the mountain birch forests was about 7.4 million m^3, which gives an average volume of only 11 m^3/ha. In the dense forests, the average volume was 26 m^3/ha.

Müller-Wille et al. (see Chap. 23) report that in Ohcejohka/Utsjoki the annual cut from private birch forest is between 12 and 23 % of the annual growth. This indicates that standing volumes are growing and that the physical supply of wood is not a limiting factor. In this area there has been a drastic change in the biomass and productivity of mountain birch forests due to the catastrophic defoliation by *Epirrita autumnata* in the mid-1960s (Kallio and Lehtonen 1973, 1975, see also Chaps. 9 and 12). This highlights the great decrease in birch forest biomass in the area from the early 1960s to the present, as well as the very poor (or effectively zero at many sites) recovery of the birch under the current climate and grazing pressure.

In Målselv and Abisko in Sweden also some of the mountain birch forests were defoliated by caterpillars during the last decade (1990–2000) (Tømmervik et al. 2001) and in these areas there were outbreaks in 2003 as well.

16.3.2 Reindeer Husbandry

For the recovery of birch in the winter grazing areas, lower reindeer densities are essential, whereas for an established mountain birch forest moderate grazing may improve growth (cf. Chap. 11). The variability of the literature review in Chapter 19 suggests that management decisions should be based on detailed information on local conditions (soil fertility, climatic conditions, vegetation type, pasture rotation, the condition of lichens in the forests etc.). This is clearly indicated in the studies of Olofsson et al. (2001) and Stark et al. (2002), who found strong site-specific effects of reindeer grazing on soil quality and nutrient turnover. Gaare and Tømmervik (2000) recommend that the optimal production (both economically and ecologically) of the lichen pasture is when the height of the lichen (thickness) is in the range 2–5 cm (lichen coverage >50 %), which means a standing biomass of 220–700 g/m^2; this calls for an efficient and carefully managed pasture rotation (see Chap. 24). Pasture rotation alone is not an efficient tool for sustainable pasture management, since reindeer herds both with and without pasture rotation can overgraze their food sources (western Finnmark). Therefore, pasture rotation and controlled reduction of grazing pressure should be applied simultaneously. So far, the effects of overgrazing are most striking in the winter pastures.

Reindeer management reports and statistics from Norway (statistical database and reports obtained from Reindeer Management Administration) covering the last 40 years show that the production of the reindeer varies a great deal, but when compared with carcass weights [slaughtering weights and production (kg) per reindeer] it seems that the recommended density for winter grazing areas (restricted use only in winter) should be in the order of 7–9 reindeer/km^2 in Finnmark, which will give an annual production of more than 10 kg/reindeer (corresponding to about 75 Euro/reindeer); this figure is considerably lower in "year-round districts" such as southern Varanger in Finnmark and Elgå in the southern Sámi district in central Norway, in the order of 2.5–3.5 reindeer/km^2. In some southern Sámi districts, however, the recommended density of the winter grazing areas (restricted use) is estimated to be in the range of 9–10 reindeer/km^2 and the yearly production per reindeer is in the order of 15–17 kg (corresponding to about 100–125 Euro/reindeer).

In Målselv, the recommended density on winter grazing areas is estimated to be only 1.5–2.0 reindeer/km^2, due to the harsh climate (snow depth and frequent rainfalls during winter), high numbers of sheep, cattle and goats, and the military activity within that particular winter grazing area (Tømmervik 2000;

Chap. 24). In conclusion, for the Norwegian areas, it seems that the reindeer pastures are in good condition and production is high in the southern Sámi districts and in the eastern part of Finnmark (southern Varanger) compared with the poorer situation concerning both pastures and production in Kautokeino (including Maze) and Karasjok districts further west in Finnmark.

In Finland, there are also distinct differences between different parts of the reindeer herding area. The special features of the northernmost (= Kaldoaivi + Paistunturit) reindeer herding districts are as follows [mainly based on Kemppainen and Nieminen (2000, 2001) and annual statistics in Poromies, cf. Chap. 19]: alternative land uses (e.g. forestry, agriculture) do not exist in practise or are very limited in this area. Consequently, there are few if any conflicting interests between reindeer husbandry and these other land uses. Reindeer ownership in Ocejohka/Utsjoki is exclusively by Sámi people. Corralling of reindeer is rare. The organization of work differs from more southern areas; "man days" spent per reindeer is smaller in the north. The estimated damage (traffic + predators) is about 0.5 % of the number of reindeer, compared with 2.5 % in the Finnish reindeer herding area as a whole. Summer pastures have low productivity/forage amount. The summer densities have been 3.5–4.5 reindeer/km^2 during recent years. The condition of winter pastures is poor. The maximum winter density allowed in this area by the Ministry of Agriculture and Forestry in Finland is now 2.2 reindeer/km^2 (cf. Chap. 11). Supplementary winter feeding has been practised less extensively than in southern Lapland, but it is increasing also in the north.

The following estimates of the income and costs of reindeer husbandry describe the average situation for the whole Finnish reindeer herding area [Filppa 2000; about 90,000 reindeer (71 % calves) slaughtered in Finland during the focal year (1998/1999)]. The specific features of Ocejohka/Utsjoki mentioned above modify these figures to some extent.

Income from reindeer husbandry (Euro per reindeer):	
From products (commercial + own use)	125.8
Compensation for loss (traffic + predation)	24.1
Other extra income	3.4
Production subsidies	26.7
Investment subsidies	9.9
Total	190 Euro/reindeer

Costs of reindeer husbandry (Euro per reindeer):	
Herding work	69.0
Maintenance	15.3
Transport	57.4
Utilities	19.1
Administration	3.7
Miscellaneous	0.2
Total	165 Euro/reindeer

From the "cost structure", it can be inferred that the economics are nowadays (due to motorization) sensitive to increased fuel prices as well as to "new costs" (e.g. supplementary winter feeding).

16.3.3 Other Limiting Factors

According to the studies carried out in the project, none of the project areas (except perhaps Abisko) seems to experience too high pressure from tourists (cf. Chap. 15), but this may easily change.

Logging, lowering of the water table for cultivation and farming may have interfered with the natural growth of meadow forests and biodiversity, especially in the river valleys. Rapid expansion of agricultural land in some parts of northern Norway, infrastructure and roads in all Fennoscandian countries (see e.g. Chaps. 15, 17, 24) have had an impact on the biodiversity in the "swamp forests" dominated by birch and willows in the river valleys, and in the valleys also dense spruce plantations which occurred in northern Norway after World War II may have caused problems concerning biodiversity, access and migration for animals and people (Werth 2001). On the other hand, as a result of the abandonment of other agricultural fields, a significant regrowth of forests has occurred, which may have led to reduced biodiversity concerning species adapted to a semi-natural Sámi landscape and agricultural landscape.

In the inner part of the county of Troms, Norway, military training has caused damage to the environment in the mountain birch forests (Norberg et al. 1998). This damage is mainly off-road traffic by motorbikes, four-wheeled cars, band-wagons and tanks, but also noise and people have disturbed and stressed the wildlife in this environment. In addition, the introduction of four-wheeled vehicles in reindeer husbandry and in recreation (cf. Chaps. 15, 19, 24) has caused damage and disturbance to the flora and fauna (Norberg et al. 1998; Gaare and Tømmervik 2000).

16.3.4 Profitability, Value Added and Markets

It has been difficult in the project to collect data on income and costs of various utilizations of the birch ecosystems considered. The main reason for this is that much of the activities are outside the market economy, providing fuelwood and other benefits for private consumption, and also that interviewed persons in general are reluctant to give private economic information. Also, it should be emphasized that for some, the economic gain from birch ecosystem utilization is so low that it is mostly negligible.

Only in the Målselv area in Norway has it been possible to obtain rather reliable data on income and value-added formation regarding birch harvests.

The birch harvest for particleboard production fluctuates according to the world market prices for particleboards and the prices of imported birch from Finland, Sweden, Russia and the Baltics. At present, this import is high and the harvest of birch in Troms and Målselv for particleboard production correspondingly low.

The harvest volume in clearfellings is about 5 m^3/ha and the average size of a harvest area is about 5 ha (range 1–20 ha). About 75 % of the birch harvest volume is from clear-fellings, the remaining 25 % is mostly from selection fellings. The average terrain transport distance for the industrial wood harvest is about 500 m (range 0–2000 m).

Based on our own data collection and information from the local forest authorities and entrepreneurs, the following average contribution to employment has been estimated from birch utilization:

Harvesting of birch (felling and terrain transport): 0.7 person hours/m^3 (range 0.5–0.9).

The harvesting costs depend on many factors such as terrain, distance to road, birch dimensions etc. On average, however, the total harvesting costs for birch used for particleboard are estimated to be (in Euro/m^3, assuming entrepreneurial operation and 2002 prices):

• Machinery investment costs (depreciation)	12.5
• Labour costs	10.0
• Diesel, oil, spare parts, other costs	5.0
Total	27.5

The price delivered roadside for birch for particleboard production in 2002 was about 32.5 Euro/m^3. The selling price of dried birch for fuelwood (after splitting, packing in 1000-l sacks and drying) was in 2002 131 Euro/m^3, excluding VAT. Assuming a combined cutting and splitting machine, this sum could on average be distributed as follows: depreciation 32 Euro, salary and profit for the forest owner 41.5 Euro (we assume all fuelwood work at the farm site is done by the forest owner), and other costs (including diesel, oil, spare parts, marketing and birch costs delivered to the farm site of 32.5 Euro) are 57.5 Euro.

With particleboard production comes, in addition, the value added created by transport to the mill and the mill production (at mill site). Based on actual accountancy figures from this production in 2001, these two activities together had a salary and profit (i.e. contribution to net value added) of 34 Euro/m^3 birch input (of this, profit was zero) and depreciation of 3.75 Euro/m^3 birch input.

The economic contribution can be quantified as contribution to gross value added, net value added and profit (the contribution to gross value added reflects the commonly used measure "contribution to national product", and the contribution to net value added reflects the commonly used measure "contribution to net national product"). Based on the above data on costs and income, these contributions of the harvesting operation and the production of fuelwood and particleboard can be estimated as (all in Euro per m^3 round-volume of birch):

	Birch for fuelwood	Birch for particleboard
Forest owner's income (profit and salary)	46.5	5.0
Labour costs	10.0	44.0
Contribution to net value added	56.5	49.0
Depreciation (capital costs)	44.5	16.0
Contribution to gross product	101.0	65.0

The figure for forest owner's income (first line) depends upon how much hired labour is assumed to be used, and in the calculations above we have assumed that all forestry operations are using hired labour. If the forest owner himself is doing the felling and terrain transport (which in fact is more likely), his profit will increase in the above calculation and labour costs will decrease correspondingly, but the contribution to net product will be the same.

It is seen that the forest owner's income is about nine times higher for fuelwood production compared to birch used for particleboard, whereas the net value added is more equal because the salary component at the factory is rather large. The depreciation component is rather high when fuelwood is produced compared to particleboard production (most likely because the capital costs at the factory are old and written off). This results in a nearly 50 % higher contribution to the gross product when birch is utilized for fuelwood compared to particleboard production.

In all project forest areas, birch is utilized as bioenergy for private non-industrial purposes, mostly for private fuelwood consumption, but also for fuelwood sales. Industrial utilization occurs in only one of the project areas (Målselv). With increasing energy prices, the contribution of bioenergy from birch (fuelwood, chips or pellets) might increase considerably, whereas the economic value of industrial utilization is not likely to increase significantly. In addition, local wood handicrafts (cf. Chap. 18) may generate some income for certain rare birch wood pieces, but demand for this is rather small.

Birch forest management activities in the project areas are rather scarce. Very few of the interviewed persons carry out thinnings to improve the stem quality and growth of remaining trees. The reason for this is that it is not profitable since the potential gain in the increase in quality is less than the extra costs involved.

Based on the present situation and the opinions expressed by the interviewed persons, it seems that in those project areas where today's cut is smaller than the annual yield, the only improvement possibility from an economic point of view is to change to a management system that harvests more birch and to do more thinnings so that larger trees with higher quality (straighter stems and less branches) can be cut (cf. Chap. 22). Increased harvest volumes depend on increased demand, and again energy prices will be decisive. Thinning has to be profitable in itself, as it is very unlikely that subsidies will be provided. The main economic limiting factor is therefore the demand for wood. Subsidies to harvesting (or to road building or machinery investment) will increase the supply of wood, and thus the harvest volumes.

The situation with respect to tourism is more complicated. Here, subsidies to road building and hotel capacity expansions will increase the supply. On the other hand, such expansions will influence the quality of the services provided, and thus also the demand. "Mass tourism" may threaten the ecological authenticity of areas near tourist centers (see Chap. 15); ecotourism still has unutilized development potential in the area. The tourism attractions and activities vary considerably in different seasons and skill is needed in developing attractive "products" and in marketing them efficiently. Co-operation among small tourist enterprises across national borders could result in enhanced and sustainable tourism in northern Fennoscandia (see Chap. 24).

It is also clear that economic limits and possibilities are closely linked to criteria C2 and C3 mentioned in Section 16.2.1 above. This illustrates that economic aspects cannot be viewed in isolation from the other criteria there.

16.4 Conclusions

The economic limits and possibilities for utilization of birch ecosystems vary between the project areas. For reindeer production, the main limit in all areas seems to be fodder (cf. Chap. 11). For birch harvest and tourism (cf. Chaps. 23 and 24), the main limitations seem to be the demand for fuelwood and industrial use of the birch, and the tourist demand for experiencing the many services that the birch ecosystems can provide. The demand for fuelwood depends heavily on the market price of energy, whereas the demand for industrial wood use depends on the demand for particleboard. The tourist demand (cf. Chap. 15) depends on many interacting factors (e.g. income, ecosystem quality, costs, other similar tourist attractions). The final limit is the balance between how much of the ecosystem one should utilize, the degree of intensity of this utilization, and how much of the area one should conserve. At the moment, however, it seems that the feasible changes in utilization will be different for different areas and sectors:

- Increased forestry (F+) might be a good alternative (depending on the markets) in the Målselv area, but in the other areas of the HIBECO project the low profitability (long transport distances + low productivity and regeneration rate) associated with conflicting interests with other sectors (reindeer husbandry, tourism) suggests that forestry should experience no changes (F0), i.e. remain at a very low level (cf. Chap. 24).

- Reindeer husbandry still faces many problems, partly due to heavy overgrazing especially in the 1980s, and consequently R0 and R– (same or decreased intensity) are the feasible alternatives in many areas. The variability in the responses of different pasture components to grazing pressure and its implications for management are discussed more thoroughly in Chapters 11 and 19.
- In most areas, there seem to be still unutilized possibilities with respect to tourism. However, if/when increased tourism (T+) is promoted, one has to be careful to find the right kind of tourism activities for these areas; tourism must not sacrifice the ecological authenticity (C3) of the area and potential conflicts with local residents should be avoided (cf. Chaps. 15 and 24).

References

Blüthgen J(1960) Der skandinavische Fjällbirkenwald als Landschaftsformation. Petermanns Geogr Mitt 104:119–144

Filppa J (2000) Porotalous tänään (in Finnish). Poromies 2000(3):8–10

Gaare E, Tømmervik H (2000) Overvåking av lavbeiter i Finnmark [Monitoring of lichen grazing areas in Finnmark]. NINA Oppdragsmelding 638:1–31

Kallio P, Lehtonen J (1973) Birch forest damage caused by *Oporinia autumnata* (Bkh.) in 1965–1966 in Utsjoki, N-Finland. Rep Kevo Subarct Res Stn 10:55–69

Kallio P, Lehtonen J (1975) On the ecocatastrophe of birch forests caused by *Oporinia autumnata* (Bkh.) and the problem of reforestation. In: Wielgolaski FE (ed) Fennoscandian tundra ecosystems, part 2. Animals and systems analysis. Springer, Berlin Heidelberg New York, pp 174–180

Kemppainen J, Nieminen M (2000) Porotalouden alueellisista eroista (in Finnish). Poromies 4–5:21–23

Kemppainen J, Nieminen M (2001) Poronhoito Suomen saamelaisalueella (in Finnish). Poromies 1:22–28

Norberg ME, Simons S, Alm T, Greve Alsos I, Palkin Jakobsen N, Lund L (1998) Prosjekt "Revegetering Karasjokfjellet" 1995–1997 (in Norwegian). Avsluttende rapport. Tromura 83

Olofsson J, Kitti H, Rautiainen P, Stark S, Oksanen L (2001) Effects of summer grazing by reindeer on composition of vegetation, productivity and nitrogen cycling. Ecography 24:13–24

Stark S, Strömmer R, Tuomi J (2002) Reindeer grazing and soil microbial processes in two suboceanic and two subcontinental heaths. Oikos 97:69–78

Statskog (1997a) Vedhogst i Finnmark (in Norwegian). Statskog Finnmark, Vadsø

Statskog (1997b) Pressemelding. Rapport for hogst i bjørkeskog gjort i 1997 på statsgrunn i Finnmark (in Norwegian). Statskog Finnmark, Vadsø

Sveinbjörnsson B, Hofgaard A, Loyd A (2002) Natural causes of the Tundra–Taiga boundary. Ambio Spec Rep 12:23–29

Tømmervik H (2000) Reinbeitekartlegging. Mauken–Blåtind–Fagerfjell. [Monitoring of the reindeer grazing areas in Mauken–Blåtind–Fagerfjell.] NINA Oppdragsmelding 641:1–34

Tømmervik H, Høgda KA, Karlsen SR (2001) Using remote sensing for detection of caterpillar outbreaks in mountain birch forests, a new interesting approach. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and biosphere series 27. UNESCO, Paris, and Parthenon, New York, pp 185–194

Werth S (2001) Key factors for epiphytic macrolichen vegetation in deciduous forests of Troms county, northern Norway: human impact, substrate, climate or spatial variation. Cand Sci Thesis, Department of Biology, Faculty Science, University of Tromsø, 89 pp

17 The Vegetation Changes and Recent Impact on the Mountain Birch Forest During the Last 40 Years

D. Thannheiser, H. Tømmervik and J. Wehberg

17.1 Introduction

The study described in this chapter focuses on vegetational changes in the mountain birch forest on the Finnmarksvidda, in the area of Máze and in the region of the Målselv valley in the county of Troms (northern Norway). The study covered a period of 37 years between 1964 and 2001. The area around the riverine settlement of Máze is predominantly covered by mountain birch, while at higher elevation and on the mountain tops, mainly treeless-fell lichen heath occurs interspersed with small islands of birch forest. A vegetational shift in the mountain birch forest plant communities is particularly noticeable in the vegetational ground layer, which includes herbs, mosses and lichens. The studies concentrated primarily on the dry birch forest type, because a floral change was not noticeable in the wetter birch forests (meadow or bog forests). Unfortunately, only a few plant sociological relevés were conducted during 1964 and 1965. After 37 years the exact sites of these relevés were revisited and considerable differences were noticed in species presence and abundance. However, this study was carried out only for the core area of Finnmarksvidda and is not decisive for the wet forest plant communities (*Rubo chamaemorei–Betuletum* and *Geranio–Betuletum*; see Chap. 3).

During the last 30–40 years, the anthropogenic development of the Finnmarksvidda with road building, growth of small settlements and construction of cabin complexes has resulted in increased pressure on the mountain birch forest (cf. Chaps. 15 and 24). The birch forest was cut in places to make way for buildings and roads, but the most severe damage to the birch forest was from harvesting firewood as well as a great increase in reindeer grazing. Additionally, the effects of climatic change play an important role (see Chap. 1).

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

17.1.1 Research Areas

The Precambrian bedrock of the Finnmarksvidda was reshaped by glacier activities during the Pleistocene. Glacio-fluvial deposits created a hilly landscape with moraines (Wielgolaski 1997).

The Finnmarksvidda is located in the transition zones between suboceanic and continental climates; however, continental influences are stronger, as shown by the annual extremes. These are indicated by hot summer periods and high-radiation weather conditions during the winter. The mean annual precipitation is 375 mm, of which 50 % falls between June and August. During the last 30 years, the annual means have risen, while evapotranspiration has been reduced due to stronger cloudiness. Thus the summer months now have more precipitation and are cooler. The suboceanic influence has shifted from the coastal region to the interior and thus has an impact on large portions of the northern Finnmarksvidda (Alm 1991; Hicks et al. 1999).

The area of Målselv is located in the inner part of Troms county in the western part of the Fennoscandian mountain chain (Wielgolaski 1997). The area is situated in the middle boreal zone but under a more oceanic influence (Tuhkanen 1984). The mountain birch (*B. pubescens* ssp. *czerepanovii*) forest extends from the Målselv fiord up to about 560 m a.s.l. It is a heath forest of polycormic and monocormic birches, 6–15 m in height, including pine (*Pinus sylvestris*) trees at the lower altitudes in the western part of the study area (Tenow 1990).

17.1.2 Methodological Considerations

In 1964 and 1965, the first author conducted vegetational surveys of the birch forests in the area around Máze on the Finnmarksvidda. Criteria for gradation were defined according to the five-level scale of Hult-Sernander (Du Rietz 1930) and the results were published in plant sociological tables (Thannheiser 1975). In 2001, the same sites were revisited and, this time, the six-level scale based on the method of Braun-Blanquet (1964) was applied. In order to obtain comparative values the results of 1964/1965 were recalculated using Braun-Blanquet's scale and they were entered into a constancy table. The tables presented here are only partial constancy tables which document the differences in the plant communities and species densities for the various survey years. More detailed classical vegetation surveys of the area during the HIBECO (Human Interactions with the mountain Birch ECOsystem) project are described in Chapter 3 and in the tables to that chapter in the enclosed CD.

Next to the classic plant sociological evaluation, the stands surveyed in 1964/1965 and 2001 were submitted to a correspondence analysis (CA) by way of an indirect gradient analysis. For this reason the surveys were sorted according to their respective floristic composition. Detrended correspondence analysis (DCA) is an indirect ordination technique that allows floristic analysis in order to find purely floristic gradients within the vegetation plots. The classification values of coverage, following Braun-Blanquet (1964), were transformed in mean values (Glavac 1996). For the analysis, using the "Multi-Variate Statistical Package 3.1" (Kovach 1986–1999), all species were regarded – even the ones that were recorded only once or had a very low cover.

Remote sensing (aerial photographs and satellite images) was used to monitor vegetation in the Máze and Målselv regions for the period 1960 to 2000 (cf. Tømmervik et al. 2004). The image processing methods followed combined unsupervised/supervised classification procedures used in earlier work in the region (Tømmervik et al. 1998; see also Chap. 4).

17.2 Vegetation Changes in the Máze Region

17.2.1 The Lichen-Rich Empetrum (Crowberry) Birch Forest (*Empetro–Betuletum pubescentis*; see Chap. 3)

This forest community is the prevalent type of forestation on the Finnmarksvidda. Its open formation reminds us of the forest of bush steppes in arid regions. The patches of birch copses reach a height of 3 to 4 m and grow widely but rather regularly spaced. Some 10 to 20 birches, with trunks of a diameter between 4 and 10 cm, form a patch. These crown-sprouting birch islands rise most often on a mound several centimetres high, and often all the trunks bend outward all around. Outside their canopy range the birch copses are encircled by dwarf bushes and mosses, while the ground inside is occupied by a contiguous light-greyish lichen cover. The ground vegetation displays a rather curious but characteristic mosaic pattern.

As can be noted in the shortened constancy table (Table 17.1), the bush layer of young birch growth increased during these 37 years. Changes can be noted as well in the herb layer, where the density of *Vaccinium vitis-idaea* and *Festuca ovina* decreased but increased for *Phyllodoce caerulea* and *Juncus trifidus*. In addition, *Deschampsia flexuosa* and *Vaccinium myrtillus* were introduced. The moss layer expanded a little over the last decades of the study. The lichen layer has changed dramatically. The dominance of *Cladonia stellaris* was lost considerably. However, the lichens *Stereocaulon* and *Cladonia uncialis* expanded, a sign of many decades of overgrazing. On the other hand, the emergence of some specimens of the fruticose lichens *Cladonia rangiferina* and *C. mitis* can be related to a reduction in grazing over the last 10 years.

Table 17.1. Shortened constancy table of the lichen-rich *Empetrum* birch forest and of the moss-rich *Empetrum* birch forest in the Máze area. Degree of presence: +, 1–10 %; *I*, 11–20 %; *II*, 21–40 %; *III*, 41–60 %; *IV*, 61–80 %; *V*, 81–100 %. Degree of abundance (in *parentheses*): +, 1 %; *1*, 1–5 %; *2*, 5–25 %; *3*, 25–50 %; *4*, 50–75 %; *5*, 75–100 %

Lichen-rich *Empetrum* birch forest			Moss-rich *Empetrum* birch forest		
No. of relevés	9	9	No. of relevés	5	5
Date	1964/1965	2001	Date	1964	2001
Tree layer					
Betula pub. ssp. *czerepanovii*	V (2)	V (2–3)	*Betula pub.* ssp. *czerepanovii*	V (2–3)	V (3)
Shrub layer					
Betula pub. ssp. *czerepanovii*		III (+–1)	*Betula pub.* ssp. *czerepanovii*		IV (1–2)
			Juniperus communis		V (1–2)
Herb layer					
Vaccinium vitis-idaea	IV (+–3)	III (1–2)	*Vaccinium myrtillus*	I (+)	V (2–3)
Festuca ovina	IV (+–1)	II (+–1)	*Cornus suecica*	I (+)	V (1–2)
Phyllodoce caerulea	II (+)	V (1–3)	*Trientalis europaea*	III (+)	V (1)
Juncus trifidus	I (+)	IIII (+–1)	*Deschampsia flexuosa*	I (+)	V (1)
Deschampsia flexuosa		III (+–1)			
Vaccinium myrtillus		III (+–2)			
Moss layer					
Dicranum scoparium	II (+)	IV (+–1)	*Pleurozium schreberi*	V (2–3)	V (3–4)
Pleurozium schreberi	II (+)	III (+–2)	*Barbilophozia lycopodioides*	III (+–1)	V (1–2)
Polytrichum alpinum/commune		III (+–1)	*Hylocomium splendens*	II (+)	V (1–2)
			Polytrichum juniperinum/strictum	III (+)	V (1–2)
			Polytrichum alpinum/commune	II (+)	V (+–1)

Lichen layer					
Cladonia stellaris	V (1–4)	V (+–2)	*Cladonia rangiferina*	V (2–3)	III (+)
Cladonia crispata	IV (+–1)	II (+)	*Cladonia stellaris*	V (+–3)	III (+)
Cladonia deformis	IV (+–1)	II (+)	*Cladonia mitis*	V (+–1)	II (+–1)
Cetraria cucullata	III (+–1)	I (1)	*Nephroma arcticum*	III (+–1)	
Stereocaulon alpinum/paschale		V (2–3)	*Cladonia deformis*	III (+)	
Cladonia uncialis		IV (+–2)	*Cladonia bellidiflora*	II (+)	
Cladonia mitis		V (+–2)	*Cladonia coccifera*	II (+)	
Cladonia rangiferina		IV (1)	*Cladonia cornuta*	II (+)	
			Cladonia ecmocyna	II (+)	
			Cetraria nivalis	III (+–1)	V (1–2)
			Peltigera aphthosa	II (+)	IV (+–1)
			Peltigera sp.	III (+)	IV (+–1)

17.2.2 The Moss-Rich Empetrum (Crowberry) Birch Forest (*Empetro–Betuletum pubescentis*; see Chap. 3)

These forest communities tend towards the *Myrtillus* birch forest based on physiognomic, ecological and sociological viewpoints. The birch patches of this community are closer together. Mosses achieve higher congruence values, but the dominance of lichens is not so strong as in the previous community. The modest but constant snow cover in winter is a determining factor for the development of the herb layer.

The shortened constancy table (Table 17.1) includes only those plant species for which the proportions have changed during the last four decades. As in the lichen-rich *Empetrum* birch forest, a stronger growth of young bushes is noticeable. The increase in species density of *Vaccinium myrtillus* and *Cornus suecica* is apparent in the herb layer. Particularly, *Cornus suecica* is an indicator for the rise in suboceanic influences on the Finnmarksvidda. Also, the much stronger dominance of the mosses *Pleurozium schreberi* and *Hylocomium splendens* indicates a greater amount of precipitation and humidity during the summer. In contrast, fruticose lichens have decreased; this is partly due to overgrazing by reindeer and partly due to O_2 limitations under ice crusts in winter (Wielgolaski 2001).

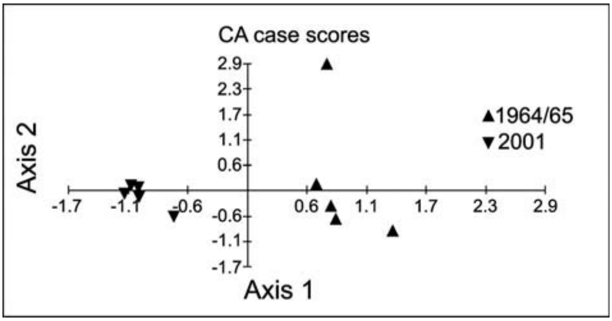
17.2.3 The Lichen-Rich Myrtillus (Bilberry) Birch Forest (*Vaccinio myrtilli–Betuletum*; see Chap. 3)

The *Myrtillus* birch forest differs in appearance from that of the *Empetrum* birch forest; because the edaphic or hygrine conditions are more suitable (cf. Chap. 2); this birch forest gives a fresher impression. The birch trunks are taller in this forest and the canopy is denser due to the short distances among the trees. The vegetational ground layer is established in complexes or patches, as in the *Empetrum* birch forest. Dwarf shrubs and mosses dominate in a 1 to 2 m wide ring around the birch island.

The plant sociological studies have shown that there is hardly any change noticeable in the plant species within the herb layer. Still, species densities have definitely augmented in the moss layer, where *Pleurozium schreberi* and *Dicranum* species were prevalent. This could have also been due to climatic changes. In contrast, the species densities of the fruticose lichens decreased significantly. This is also a consequence of overgrazing, for which the occurrence of *Cetraria nivalis* is a good indicator. Recently, small specimens of fruticose lichens (*Cladonia rangiferina*, *C. mitis*) have been found; their occurrence is connected to decreased grazing in recent years.

By using multivariate numeric methods, it is possible to make a clear comparison of plant sociologic surveys from the two various periods about 40

Fig. 17.1. Correspondence analysis (*CA*) of the lichen-rich *Myrtillus* birch forest



years apart (1964/1965 and 2001). In the correspondence analysis (Fig. 17.1), the changes in species densities of the plants show up clearly, and the floristic composition was clearly different in 1964/1965 compared to 2001.

17.2.4 The Moss-Rich *Myrtillus* (Bilberry) Birch Forest (*Vaccinio myrtilli–Betuletum*; see Chap. 3)

In this forest community, crown-sprouting birches with multiple trunks reach an average of 5 to 6 m in height; the distances among patches are smaller. Single-stemmed individuals (monocormic) also occur. The sparse occurrence of lichens only rarely provides an indication of the complex character of the soil layer (see Chap. 2). The phenotype of the trees has changed: the birches are much stronger and taller, at times forming a closed canopy.

In this forest community, the difference in species density after 37 years is not as serious as in the previously discussed communities. The stands give a more stabile impression, according to the plant sociological studies, although species such as *Calamagrostis lapponica*, *Trientalis europaea* and *Diphasiastrum alpinum*, which were observed with low congruence values in 1964/1965, did not occur at all in 2001. Noticeable was the higher dominance of *Cornus suecica* in the herb layer. In the ground layer, only the mosses *Hylocomium splendens* and *Dicranum fuscescens* show a noticeably higher dominance. The last mentioned indicators also point to climatic change; in contrast, overgrazing does not provide any signs, because lichens play a lesser role in this community.

17.2.5 The *Cornus–Myrtillus* (Dwarf Cornel–Bilberry) Birch Forest (*Corno–Betuletum*; see Chap. 3)

This forest community resembles the moss-rich *Myrtillus* birch forest. The phenotype of the trees has changed even more because individually growing birches (monocormic) often emerge here, forming an almost completely closed canopy, probably partly because of more nutrient-rich soil (cf. Wielgolaski and Nilsen 2001). The herb layer consists of a dense layer of ankle- to knee-high leafy plants with an underlying dense moss layer.

In this forest community, the herb layer changed significantly between 1964 and 2001. The vegetational ground layer is now 70 to 80 % dominated by *Cornus suecica* (Table 17.2). This shows that this vascular plant increased by 20 to 25 %; in 1964, the level of observed congruence was 45 % (Thannheiser 1975). Also, *Vaccinium myrtillus* and *Linnea borealis* have expanded their range. The moss layer also spread during the last 37 years, particularly *Hylocomium splendens*, which extended to the detriment of *Pleurozium schreberi*. North of Máze, the former camping grounds of reindeer nomads have been invaded by *Cornus suecica*. *Vaccinium myrtillus* can no longer compete in these damaged areas. In 2001, lichens were seen only sporadically. The average snow cover during winter has increased. This was noted in 2001 when the range border of *Melanelia olivacea* (an indicator lichen on birch trunks) was observed at a height of 80 to 100 cm, along with the increased appearance of *Juniperus* bushes (which absolutely need snow cover). By comparison, in 1964, the *Melanelia olivacea* border was only at about 60 cm. This remarkable shift in vegetation seems to indicate climatic change (Fig. 17.2).

Table 17.2. Shortened constancy table of the moss-rich *Cornus–Myrtillus* birch forest in the Máze area

No. of relevés Date	5 1964/1965	6 2001
Tree layer		
Betula pub. ssp. *czerepanovii*	V (3–4)	V (3–4)
Shrub layer		
Juniperus communis	III (1)	V (1–2)
Herb layer		
Cornus suecica	V (3)	V (4–5)
Vaccinium myrtillus	V (1–2)	V (2–3)
Linnea borealis	III (+)	V (+–1)
Moss layer		
Pleurozium schreberi	V (2–3)	V (1–3)
Hylocomium splendens	V (1)	V (2–4)
Polytrichum alpinum/commune		IV (1–2)
Lichen layer		
Cladonia rangiferina	V (+–1)	I (1)
Peltigera aphthosa	V (+–1)	I (+)
Nephroma arcticum	IV (+)	
Cladonia crispata	III (+)	

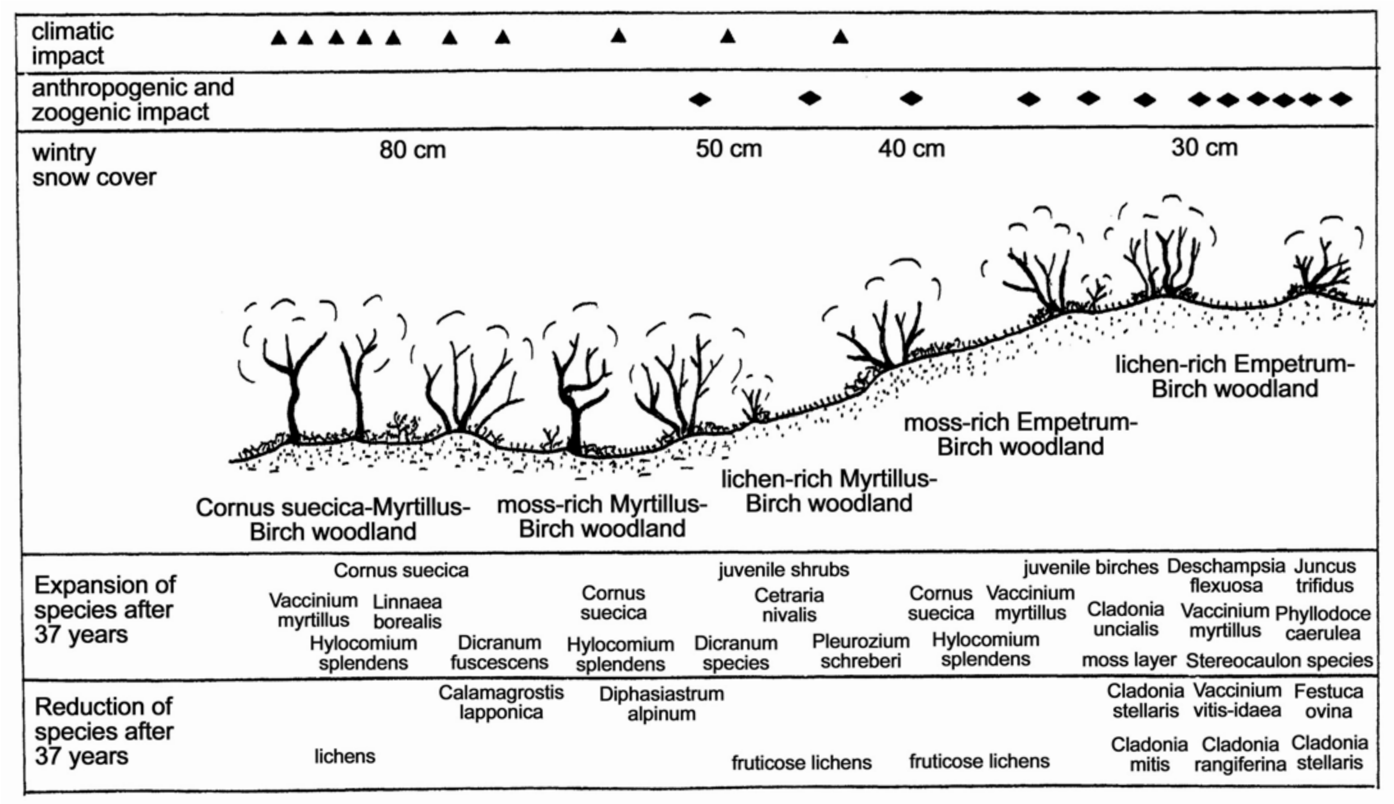


Fig. 17.2. Idealized profile of the mountain birch forest on the Finnmarksvidda

17.2.6 Monitoring Vegetation Change in the Máze Region

Vegetation in the Máze region was monitored for the period 1960 to 2000 using aerial photographs (Lyftingsmo 1965) and satellite images (Landsat MSS/TM). The total area is about 10,786 km^2. Prior to the present study in the HIBECO project (Thannheiser and Müller-Wille 2003), fieldwork had been carried out by the authors and others in 1961 (Lyftingsmo 1965), 1965 (Thannheiser 1975) and 1989–2002 (Johansen and Tømmervik 1993; Gaare and Tømmervik 2000; Tømmervik et al. 2004). Satellite image interpretations and reports were made by Johansen and Tømmervik (1993), Johansen and Karlsen (2000), and Tømmervik et al. (2004) using Landsat MSS/TM images from 1973, 1980, 1988, 1996 and 2000. The main conclusion of this study is that the area of birch forests increased from about 22.3 % in 1978/82 to 32.3 % in 2000 (Table 17.3, Fig. 17.3). Table 17.3 shows that the *Cornus–Myrtillus* birch forests and the moss-rich *Myrtillus* birch forest increased from 1.9 to 7.4 % during the period 1961 to 2000. The moss-rich *Empetrum* birch forest increased from 7.0 to 12.1 % during the same period.

For the mountain heaths and the tundra, the main change is in the lichen-dominated mountain heaths (dwarf birch lichen heaths with lichen cover >50 %), which decreased from 32.1 % in 1961 to 3.5 % in 2000. In the same period, the dwarf birch *Empetrum–Myrtillus* mountain heaths with removed or reduced lichen cover increased from 9.4 to 28.2 % (Table 17.3). The condition (coverage and thickness) of the lichen-dominated vegetation cover types reduced significantly from 1961 to 2000 (Gaare and Tømmervik 2000).

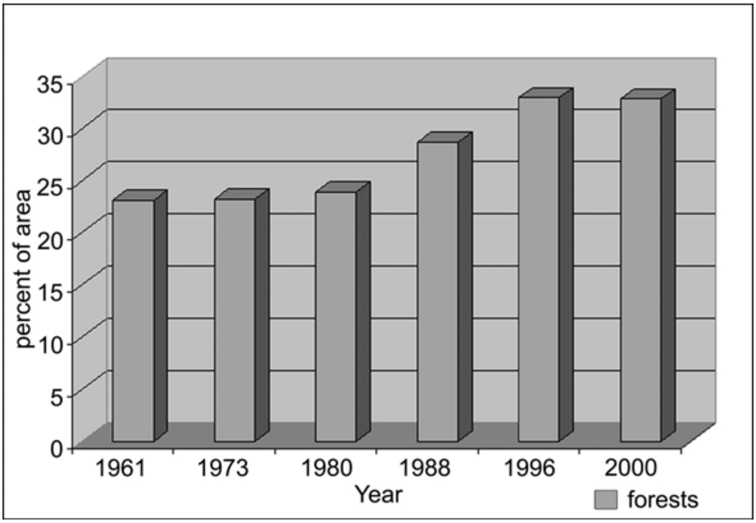


Fig. 17.3. Area of the forests as a percentage of the total area in Máze during the period 1961 2000

Table 17.3. Area of the main vegetation communities of the Máze area 1961 to 2000 (in %). Total area is 10,786 km^2

Vegetation cover type	1961	2000
Pine forests/mixed forests	0.7	0.7
The *Cornus–Myrtillus* birch forests and moss-rich *Myrtillus* birch forest	1.9	7.4
Meadow forests	4.0	4.7
The moss-rich *Empetrum* birch forest	7.0	12.1
The lichen-rich *Empetrum* and *Vaccinium* birch forest subtype lichen cover >50 %	9.4	8.1
Poor fen/bog	7.1	6.9
Intermediate fen	6.6	8.5
Dwarf birch–*Empetrum*–*Vaccinium myrtillus* subtype (lichen cover <25 %)	4.4	4.0
Dwarf birch–*Empetrum*–*Vaccinium myrtillus* subtype (lichen cover 25 to 50 %)	2.0	3.2
Dwarf birch–*Empetrum*–*Vaccinium myrtillus* subtype (lichen cover >50 %)	5.1	0.0
Dwarf birch–*Empetrum*–lichen subtype (lichen cover <25 %)	5.0	9.1
Dwarf birch–*Empetrum*–lichen subtype (lichen cover 25 to 50 %)	5.9	0
Dwarf birch–*Empetrum*–lichen subtype *Cladonia stellaris* (lichen cover >50 %)	27.1	3.5
Dwarf birch–*Empetrum*–lichen subtype *Cladonia stellaris* (overgrazed areas)	0	15.1
Tall-herb meadow and scrub	4.2	4.6
Meadow vegetation and pasture land (cows/sheep)	0.1	0.1
Snowbed vegetation (including barrens and parts of the bilberry heaths)	2.3	3.2
Barren land and boulder	1.9	3.3
Lakes, rivers, etc.	5.3	5.3
Total	100.	100.

17.2.7 Monitoring Vegetation Change in Målselv

In Målselv, vegetation was monitored using satellite images (Landsat MSS/TM and IRS-1D) from 1978, 1982, 1990 and 1998 and in fieldwork. Fieldwork was conducted by the second author (Tømmervik) and others (Lyftingsmo 1974; Villmo 1979, 1990; Johansen and Tømmervik 1992; Tømmervik 2000) in 1975, in 1976, 1979, 1991 and 1999–2001, respectively. The main result of this study shows that the extent of birch forests consisting mainly of *Cornus–Myrtillus* birch forests and moss-rich *Myrtillus* birch forests increased from ca. 16 % in 1978–1982 to ca.18 % in 1999, while the mixed pine–birch forests increased from ca. 2 to 4 % in the same period (Table 17.4). The dwarf shrub woodland (mainly the *Empetrum* and *Vaccinium* birch forests) increased from ca. 6.5 to ca. 8 % in the period 1978–1999. In the most continental areas of Målselv (Dividalen), these forests were defoliated and reduced due to severe caterpillar attacks in an area of more than 45 km^2 in 1994–1995 (Tømmervik et al. 2001). The dwarf birch–mountain crowberry–bilberry subtype with reduced lichen cover (lichen cover <30 %) increased from 1978 to 1990 due to heavy grazing by reindeer and sheep, military activities or other reasons. From 1990 to 1999, this vegetation formation was reduced, while the lichen-dominated vegetation formation, dwarf birch–mountain crowberry–lichen subtype *Cladonia alpestris* (lichen cover >30 %) increased in the same period.

Table 17.4. Area of the main vegetation communities in the Målselv area 1978/1982 to 1999 (in %)

Vegetation cover type	1978/1982	1990	1999
Pine forests/mixed pine–birch forests	2.1	2.8	3.9
Bilberry forests/meadow forests (mainly *Cornus–Myrtillus* birch forests and moss-rich *Myrtillus* birch forest)	15.9	16.0	18.2
Dwarf shrub woodland (lichen-rich *Empetrum* and *Vaccinium* birch forest)	6.5	6.2	8.1
Fens and mires	4.6	4.6	5.2
Dwarf birch–mountain crowberry–bilberry subtype (lichen cover <30 %)	23.9	30.0	27.1
Dwarf birch–mountain crowberry–lichen subtype *Cladonia alpestris* (lichen cover >30 %)	5.4	0.8	2.9
Meadow vegetation/snowbed vegetation	10.7	14.7	11.5
Barren land/exposed heaths, boulder and snow	24.1	18.1	16.3
Lakes, rivers, etc.	6.8	6.8	6.8
Total	100	100	100

The condition of the lichen grazing pastures for reindeer (cf. Chap. 11) was also mapped in order to compare the present condition with the condition of the same pastures in 1976–1978 and 1991 (Villmo 1979, 1990; Johansen and Tømmervik 1992; Tømmervik 2000). The results of this investigation show that the condition (coverage and thickness) of the winter grazing pastures with lichen content improved from 1991 to 1998–2000. Possible reasons for the improved situation could be, among other things:

- change in military activities, e.g. reduced military activity during the snow-free months (reduced activity of off-road vehicles);
- reduced numbers of sheep and reindeer within the area due to military activities (winter) and increased number of predators (lynx, wolverine and brown bear);
- changes in management of reindeer due to increased military activity in the military training areas during the winter;
- climate conditions (heavy snow falls during the winter preventing reindeer from utilizing the lichens).

The reasons for the increase in the area of the forests in Målselv may be due to reduced grazing (sheep, reindeer, goat) during the last decades, increased summer precipitation over the last 40 years and elevation of the timberline (cf. Chaps. 1, 5, 8, 16, 25) due to reduced grazing, climatic change and deposition of nitrogen. A key species among the herbs in the birch forest is the dwarf cornel (*Cornus suecica*), which has increased significantly in frequency and coverage in the inner part of the Målselv area over the last 40 years (Lyftingsmo 1974; Tømmervik 2000). *C. suecica* is an indicator of suboceanic influence in these more or less continental areas. Precipitation during the growing season has increased by 15 % over the last 40 years at the weather station in Dividal. The increase in precipitation was especially significant in June with an increase of 40 %. The increase in *C. suecica* could also be an effect of the decrease in bilberry (*V. myrtillus*) in the area. In forests of dwarf shrub type, several studies show that bilberry and crowberry are declining in the face of competition from, e.g., wavy hair grass (*Deschampsia flexuosa*). This is found to be an effect of nitrogen since these species are slow-growing and adapted to nutrient-poor systems (Lipson et al. 1996; Nordin et al. 1998). Also, insect and fungal attacks on bilberry increase when nitrogen deposition increases (Nordin et al. 1998).

17.2.8 Discussion

Through this study comparing two time periods 37 years apart, vegetational changes were determined in the different mountain birch forest communities on the Finnmarksvidda, in particular with respect to species abundance. Furthermore, by 2001, species had appeared that had not been registered 37 years ago (Fig. 17.1). The apparently stable climax stages react slowly to external factors and, often, shifts in plants are only visible after decades. The causes lie with climate change and anthropogenic impact. Reindeer grazing has had an impact on the vegetation cover on the Finnmarksvidda (cf. Chap. 11), particularly in the region of Máze between 1960 and 1990. During that time, this area was used as spring and autumn pasture, and the high density of animals caused considerable strain due to overgrazing (Johansen and Karlsen 1996; Hass and Thannheiser 2002).

The most apparent change is the disappearance of the fruticose lichens (*Cladonia mitis*, *C. rangiferina*, *C. stellaris*) in the lichen-rich *Empetrum* birch forest (Fig. 17.2). During the last decades, the fruticose lichens did not regenerate because they were heavily grazed as winter forage for the reindeer; instead crustose lichens such as *Stereocaulon* sp. and *Cladonia uncialis* expanded (Dierssen 1996). It was observed that in single cases, young, small specimens of *Cladonia mitis* and *C. rangiferina* can grow back with reduced grazing and take the position of the former large fruticose lichens. However, increased precipitation is also detrimental to the lichens. A higher temperature, particularly in spring, may also cause more ice crusts, unfavourable for the survival of fruticose lichens (Wielgolaski 2001). Also notable is the increased appearance of some vascular plants such as *Deschampsia flexuosa* and *Juncus trifidus*, as well as *Phyllodoce caerulea*. The portion of *Vaccinium myrtillus* increased in the *Empetrum* birch forest, where the moss layer (*Hylocomium splendens* and *Pleurozium schreberi*) also expanded.

No very great change was noted in the *Myrtillus* birch forests. Remarkable, however, is the greater abundance of mosses and the immigration of *Cornus suecica*. Particularly in the *Cornus suecica–Myrtillus* birch forests, *Cornus suecica* occupied the herb layer almost completely. The changes in the vegetation cover of the *Myrtillus* birch forests are not so much due to anthropogenic influences; rather they can be seen as signs of climatic change (Fig. 17.2). The vascular plant *Cornus suecica* counts as an indicator of suboceanic influence because its main distribution area is along the coast in Finnmark, although it is spreading more and more inland.

The intensified advance of *Cornus suecica* into the interior of the Finnmarksvidda indicates that precipitation has increased during the summer season. The monthly precipitation during the growing season between May and August was 46 mm during a 30-year period between 1935 and 1964; over the last 30 years (1972 to 2001), the precipitation rose to 50 mm. In the last 70 years, precipitation has risen in general (based on the measurements at the weather station at Suoluvuobmi). It needs to be stressed here that other additional factors (cloud cover, evaporation, depth of snow cover) play a role in the formation of the suboceanic climate. Local precipitation during summer can have an impact on the water budget, as shown by the precipitation maps of Tveito et al. (2001) on which higher precipitation levels were recorded for the research area. Also, deeper snow cover, as observed in the *Cornus–Myrtillus* birch forest, was documented. This condition contributes to changes in the spring water budget for the soil (cf. Chap. 1).

After about 40 years the whole physiognomy and structure of the birch forest have changed. In all the forest communities increased growth of young birch was observed. The *Myrtillus* birch forests have become denser and are avoided by reindeer; this is seen by the infrequent use of paths. Especially in *Myrtillus–Cornus* forests, the canopy and biomass have increased. Generally, the increase in the mountain birch forest has been stronger at Finnmarksvidda than in Målselv (cf. Chaps. 4 and 16).

Based on these studies, one can advance the prognosis that only up to 50 % of the fruticose lichens can regenerate within 40 years if the current climate prevails and the number of reindeer are kept at the same level. However, should the climatic conditions continue to change, the fruticose lichens could be reduced to 30 % of their original coverage. It is also estimated that one third of the vegetational layer will then be *Empetrum* birch forests with moss and vascular plants, and the crustose lichens will be reduced to 30 %. *Cornus suecica* and mosses will expand even farther into the *Myrtillus* birch forests.

The increase in extent and the changes in the birch forest communities in the Máze region may have different and interrelated causes:

- increased winter grazing due to increased number of reindeer during the period 1961 to 2000;
- grazing and trampling of the winter pasture areas during the summer time;
- increased summer precipitation over the last 40 years;
- milder winters with more ice crusts killing fruticose lichens;
- increased deposition of nitrogen through precipitation;
- elevation of the timberline due to climatic change (precipitation and temperature) and removal of the lichen cover.

One of the causes, deposition of nitrogen, deserves some comments regarding the increase of the birch forests. Several studies point to an increase in forest growth over the course of the 20th century, both in Sweden and in Europe generally (Spiecker et al. 1996); atmospheric deposition of inorganic nitrogen may be a contributory factor (Cannell et al. 1998). The results of the pan-European project 'Growth Trends in European Forest', which were published in 1996, indeed showed that the rate of forest growth has increased at many sites in Europe (Spiecker et al. 1996). The causes for this increase have now been investigated and the results indicate that increased nitrogen deposition from the atmosphere is the main cause of the observed increases in forest growth. Such an increase in growth is to be expected in a situation where nitrogen is a growth-limiting factor, as is the case for the majority of forest land and especially the birch forests in Fennoscandia (Nohrstedt 1993). The increase in the nitrogen level in trees is caused by increased human-induced nitrogen deposition, maybe speeding recovery from past land uses. Numerous field experiments in the Nordic countries have shown that additions of inorganic nitrogen often boost forest growth (Sikström and Nohrstedt 1995). Changes in climate and increased atmospheric CO_2 concentration seem to be of secondary importance in causing the observed growth acceleration compared to increased nitrogen nutrition (Cannel et al. 1998). Several authors report, however, that in the future the nitrogen effects will diminish and CO_2 and climate change will be the major causes of increases in the forest growth rate expected in coming decades, especially in northern Europe.

Increased growth and accumulating wood volume in the forests indicate that if the structure of the forests is to be maintained, changes in the intensity of management practices, e.g. more frequent or intensive thinnings, are needed. Sustainable forest management (cf. Chap. 23) and reindeer management (cf. Chap. 19) in the future may require more attention to the nutritional budget of forest ecosystems.

17.3 Linear and Localized Development on the Finnmarksvidda

Máze, with more than 300 inhabitants, is the centre for many small settlements connected by roads that have improved markedly in the last decades (Fig. 17.4). In the late 1950s, a new two-lane all-season gravel road was begun from Alta; it reached Suoluvuobmi in 1960, Máze in 1964 and Kautokeino in 1966. In 1974 to 1976, an asphalted connection was constructed from Máze south to Karasjok via the homesteads of Lappoluobbal, Suodnjo, Garggoluobbal, Vuoddasluobbal and Suodnjuratto. Because of this connection, many families, both Reindeer Sámi and non-Sámi, settled in Lappoluobbal and Garggoluobbal over the past 25 years.

The development in the last 30 years of two large cabin complexes contributed to the growth of the road network and of small settlements on the Finnmarksvidda. In 1994, there were only five cabins around Máze; they were used as shelters for hunting (Fig. 17.4). In the mid-1970s weekend cabins, owned by Norwegians from Alta and Hammerfest, began to appear north of Suoluvuobmi and south of Máze along the new road. The municipal authorities in Kautokeino tried to limit construction in these two areas. Although they were partially successful in keeping construction confined, they were not able to completely control development (Fig. 17.4). Most of the cabins standing isolated on the Finnmarksvidda are used by Sámi as weekend cabins and for hunting or fishing. Around Suoluvuobmi and Salggonjavrre there are a number of summer houses owned by Reindeer Sámi.

The expansion of the road network (cf. Chaps. 15, 16, 23–25) and small permanent settlements as well as the construction of cabin complexes have resulted in many people residing periodically on the Finnmarksvidda, and in other regions of northern Fennoscandia, e.g. in hotels in Swedish and Finnish Lapland (see Chaps. 15 and 24). The preferred building sites for these cabins on the Finnmarksvidda have been in the birch forest. The clearing for these

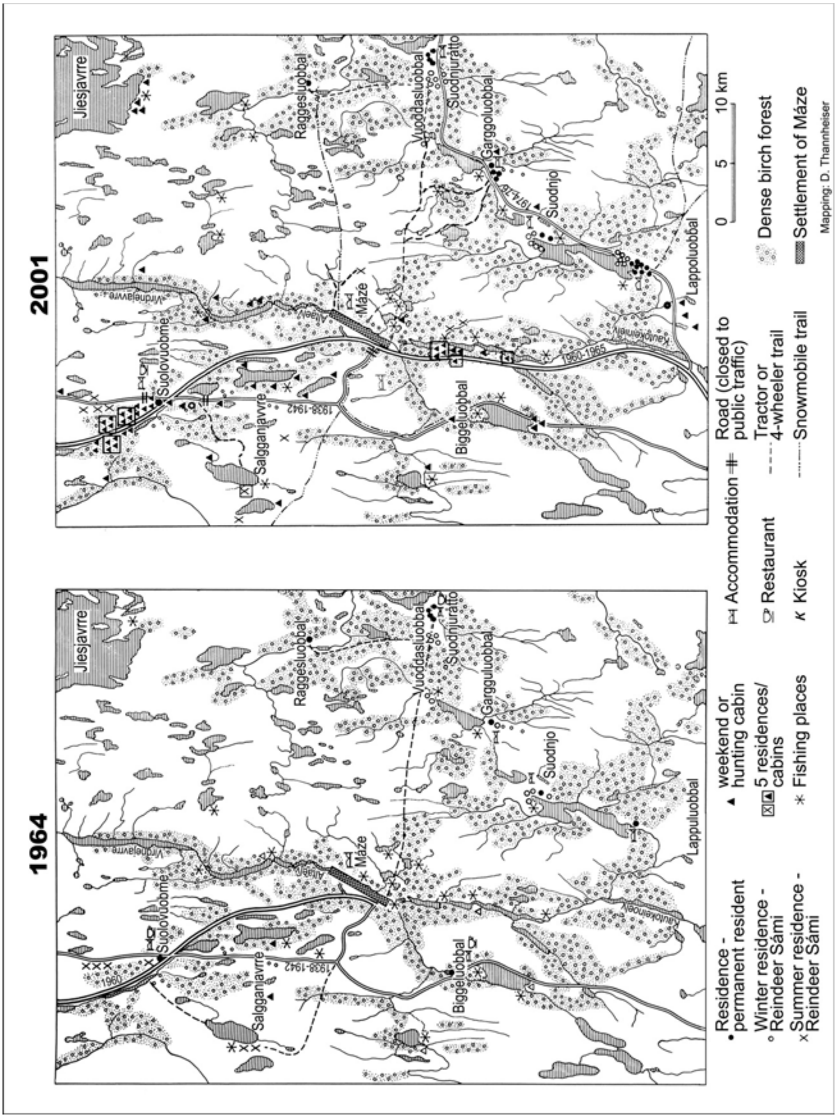


Fig. 17.4. Anthropogenic development of the Finnmarksvidda from 1964 to 2001

building sites and the construction of roads to them have had a large impact on the birch forest. The most noticeable damage and changes to the birch forest have been caused by the removal of birch for firewood.

Acknowledgement. The authors are grateful to Linna Weber Müller-Wille (St. Lambert, Quebec, Canada) for translation from German and for English language editing.

References

Alm T (1991) Floraen in Finnmark (in Norwegian). Polarflokken 15(1):45–97

Braun-Blanquet J (1964) Pflanzensoziologie, 3rd edn. Springer, Berlin Heidelberg New York

Cannel MGR, Thornley JHM, Mobbs DC, Friend AD (1998) UK conifer forests may be growing faster in response to increased N deposition, atmospheric CO_2 and temperature. Forestry 71:277–296

Dierssen K (1996) Vegetation Nordeuropas, 1. Aufl. Ulmer, Stuttgart

Du Rietz G (1930) Vegetationsforschung auf soziationsanalytischer Grundlage. Handb Biol Arbeitsmeth 11:293–480

Gaare E, Tømmervik H (2000) Monitoring of lichen grazing areas in Finnmark (in Norwegian). NINA Oppdragsmelding 638:1–33

Glavac V (1996) Vegetationsökologie – Grundfragen, Aufgaben, Methoden. Gustav Fischer, Stuttgart, 358 pp

Hass K-T, Thannheiser D (2002) Siedlungs- und Wirtschaftsstrukturen in Masi (Nordnorwegen). Hamb Veg Geogr Mitt 15:1–62

Hicks S, Jalkanen R, Aalto T, McCaroll D, Gagen M, Pettigrew E (1999) Forest response to environmental stress at timberline. EU-Project, University of Oulu, 175 pp

Johansen B, Karlsen SR (1996) Reingjerder i Finnmark – virkning på flora, vegetasjon og endringer av vegetasjonsdekket (in Norwegian). NORUT IT Report, IT/2033/01-96, pp 1–123

Johansen B, Karlsen SR (2000) Finnmarksvidda – kartlegging og overvåking av reinbeiter – status 1998 (in Norwegian). NORUT IT Report, IT/546/1-00, pp 1–68

Johansen B, Tømmervik H (1992) Reinbeitekartlegging i Mauken/Blåtind (in Norwegian). FORUT IT Report, IT/2022/2–92, pp 1–32

Johansen B, Tømmervik H (1993) Finnmarksvidda -Vegetasjonskartlegging. Vegetasjonstyper, lavbeiter og endringer i lavdekket innen reinbeitedistrikt 30 og 31, Finnmarksvidda (in Norwegian). FORUT IT Report, IT/2020/1-93, pp 1–40

Kovach W (1986–1999) Multi-variate statistical package, version 3.1. Kovach Computing Services, Pentraeth

Lipson DA, Bowman WD, Monson RK (1996) Luxury uptake and storage of nitrogen in the rhizomatous alpine herb, *Bistorta bistortoides*. Ecology 77:1277–1285

Lyftingsmo E (1965) Norske fjellbeite Bind XV Oversyn over Fjellbeite i Finnmark (in Norwegian). Det Kgl Selskap for Norges Vel 15:1–367

Lyftingsmo E (1974) Norske fjellbeite Bind XIV. Oversyn over Fjellbeite i Troms og nordre deler av Nordland (in Norwegian). Det Kgl Selskap for Norges Vel 14:1–344

Nohrstedt H-Ö (1993) Den svenska skogens kvävestatus (in Swedish). Redogörelse no 8. SkogForsk, Uppsala

Nordin A, Näsholm T, Ericson L (1998) Effects of simulated N deposition on understorey vegetation of a boreal coniferous forest. Funct Ecol 12:691–699

Sikström U, Nohrstedt H-Ö (1995) Näringstilgång som kritisk faktor för trädens tilväxt och vitalitet – erfarenheter från fältforsök (in Swedish). Kungl Skogs Lantbruksakad Tidskrift 134:118–128

Spiecker H, Mielikainen K, Kohl M, Skovsgaard JP (eds) (1996) Growth trends of European forests. Studies from 12 countries. Springer, Berlin Heidelberg New York

Tenow O (1990) Altitudinal and within-crown distribution of insect grazing on mountain birch (*Betula pubescens coll.*) in SW Greenland and NW Norway. Meddr Grønland Biosci 33:35–42

Thannheiser D (1975) Vegetationsgeographische Untersuchungen auf der Finnmarksvidda im Gebiet von Masi/Norwegen. Westfäl Geogr Stud 31:1–178

Thannheiser D, Müller-Wille L (eds) (2003) Human interactions with the mountain birch forest ecosystem in northern Fennoscandia. Hamb Veg Geogr Mitt 17:43–65

Tømmervik H (2000) Reinbeitekartlegging Mauken – Blåtind – Fagerfjell (in Norwegian). NINA Oppdragsmeld 641:1–34

Tømmervik H, Johansen ME, Pedersen JP, Guneriussen T (1998) Integration of remote sensed and in-situ data in an analysis of the air pollution effects on terrestrial ecosystems in border areas between Norway and Russia. Environ Monit Assess 49:51–85

Tømmervik H, Høgda KA, Karlsen SR (2001) Using remote sensing for detection of caterpillar outbreaks in mountain birch forests, a new interesting approach. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and biosphere series 27. UNESCO, Paris, and Parthenon, New York, pp 185–194

Tømmervik H, Johansen B, Tombre I, Thannheiser D, Högda KA, Gaare E, Wielgolaski FE (2004) Vegetation changes in the Nordic mountain birch forest: the influence of grazing and climate change. Arct Antarct Alpine Res 36:322–331

Tuhkanen S (1984) A circumpolar system of climatic-phytogeographical regions. Acta Bot Fenn 127:1–50

Tveito OE, Førland EJ, Alexandersson H, Drebs A, Jonsson T, Tuomenvirta H, Vaarby-Laursen E (2001) Nordic climate maps. Rep 06/01. Det Norske Meteorologiske Institutt, Oslo

Villmo L (1979) Beiteundersøkelse Distrikt nr 27 Mauken, Troms fylke (in Norwegian). Statskonsulenten i reindrift, Tromsø, 86 pp

Villmo L (1990) Beiteundersøkelse for Mauken reinbeitedistrikt (in Norwegian). Mimeograph. Tromsø, 27 pp

Ward JH (1963) Hierarchical grouping to optimize an objective function. J Am Stat Assoc 58:236–244

Wielgolaski FE (1997) Fennoscandian tundra. In: Wielgolaski FE (ed) Polar and alpine tundra. Ecosystems of the world 3. Elsevier, Amsterdam, pp 27–83

Wielgolaski FE (2001) Field- and bottom layer vegetation mat transplantation: a method to simulate possible effects of climate change? Skógræktarritið 2001:167–170

Wielgolaski FE, Nilsen J (2001) Coppicing and growth of various provenances of mountain birch in relation to nutrients and water. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. Man and biosphere series 27. UNESCO, Paris, and Parthenon, New York, pp 77–92

18 Sámi Approaches to Mountain Birch Utilization in Northern Sápmi (Finland and Norway)

M.S. Aikio and L. Müller-Wille

18.1 Introduction: Control, Access and Sustainability of Mountain Birch Forests

The mountain birch forests within Sápmi, the cultural and socio-economic home region of the Sámi in northernmost Europe, have received much attention in aboriginal, scientific and industrial circles during recent times. This attention is a reaction to the changing human dimensions and environmental conditions related to the utilization of a specific natural resource, the birch. This is expressed by different emerging internal and external interests that converge in the same space at the same time. The changing environmental circumstances caused by climatic and global change add an encompassing umbrella to the challenges that local people face in northern circumpolar regions.

The evolving developments in the northern forests (birch, pine or spruce) are part of a global process in which the diverse human–forest relationships are examined, stressing the value of indigenous or local knowledge and practices by proposing innovative approaches to sustainable development and resource management as a reaction to the effects of economic and political globalization. It is understood that forest environments have been and continue to be one of the maintaining organic bases for human existence. They require careful attention and assessment if they are to continue to be part of humankind's livelihood. The northern forests are no exception. These boreal forests are an ecotone, a transitional zone. They are considered to be a distinct vegetational type divided into the upper timberline (cf. Chap. 1) between the mountain birch forest and tundra, but also with a lower timberline (Cox and Moore 1993).

In northernmost Europe, the Sámi have been "boreal forest dwellers" for time immemorial, i.e. after the last deglaciation, using the emerging forest resources in a variety of ways in "…hunting, trapping, reindeer herding, for food and fuel gathering, and the extraction of raw materials" (Baer 1996, p. 19). Up until today, times and conditions have changed considerably with

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

the immigration of other peoples and their different livelihoods into Sápmi. Northern forest resources gradually have become of interest not only to the local peoples but also to external, either public or private, commercial and industrial institutions which, next to northern agricultural expansion, have pushed the limits of economic forestry farther and farther into the timberline forests (cf. Hustich 1946, 1979; Chap. 16).

By the late 20th and early 21st century, the issues around forest utilization have emerged into a full-scale "timber-line conflict" that alludes to "the societal transformation of nature", shifting concepts of "wilderness", "the conservation of wilderness and the industrial exploitation of natural resources" as well as the polarization of "ethnic tensions", i.e. between Sámi and Finns (Lehtinen 1991). These processes are part of contemporary Finnish forestry policies, their conceptualization and implementation (Lehtinen 1991).

Within the broader context, a discussion has arisen that questions the validity of the very concept of "knowledge and science" in the interface between aboriginal and western-oriented societies and their intellectual history and culture. In short, whose knowledge and science has the power of influence to shape ideas and to develop policies for resource utilization? In Sápmi, Helander (1992, 1993, 1996a,b, 1999) and Kalstad (1996, 1997) have raised this issue, highlighting the basis of holistic Sámi knowledge and values by taking Sámi concepts and contrasting them with the more rigid, systematic and linear approach of western-oriented science.

In this discussion, both facts and arguments need to be carefully proven in their truthfulness to reality without falling into the trap of right and wrong or black and white. This paradigm holds particularly true when spirituality and intuition are seen as one way of explaining "scientific truth". This does not deviate from the assumption that "knowledge" among the Sámi, as in other societies, is holistic in principle, combining both nature and culture in a circular fashion interrelating people and the environment through the daily application of society's knowledge (Aikio 1990). This approach accepts limitations set by nature; thus knowledge and understanding are guided to attain survival at the minimum level achievable in situations where decisions are made independent from externally converging forces and interests.

By the 21st century, the circumstances have changed to a mixture of internal and external exchanges of ideas, innovations and decision-making processes. In resource utilization, this means that integrative or collective models might be found to alleviate conflicts. Be it reindeer herding (Kalstad 1997), tourism (Aikio 1998) or birch utilization (Mattson 1995), the issues are fairly similar.

In Finland in the 1990s, the conditions for the utilization of timberline forests throughout the circumpolar boreal belt were discussed by Veijola (1998) who represents the public institution of Metsähallitus (Finnish Forest and Park Service) and put the future of boreal forests within the context of rapidly expanding industrial forestry.

International meetings were held to discuss topics such as "sustainable development in the northern timberline forests" (Kankaanpää et al. 1999), "sustainable development in the Arctic" (Senkpiel et al. 1998) and "northern timberline forests" (Kankaanpää et al. 2002). These meetings brought together a wide range of people representing aboriginal and local northern peoples, scientists and practitioners. These publications provide a diversity of views of what "sustainability" means for whom under what circumstances and in which specific area. The question of how the northern mountain birch forests should be used as a resource by whom and for what has not and cannot receive one solid answer. The following discussion in this chapter will make this apparent by presenting the Sámi points of view on these issues.

This chapter analyzes results of intensive interviews which the first author conducted with Sámi in Sápmi on the Finnish and Norwegian side of the River Deatnu (Finnish Teno, Norwegian Tana) in 2001. The interview questions were formulated in joint discussions between local residents and the research team (cf. CD in back-pocket).

18.2 Human–Birch Relations: Holistic Approach to the Environment

This study focused on the continuing use by and the importance of the mountain birch forests to local Sámi people who utilize the latitudinal and altitudinal fringes of the birch within the municipality of Ohcejohka (Utsjoki). An earlier study with a similar focus looking at human impact on the northern timberline birch forest was conducted in Ohcejohka in the mid-1980s, drawing on interviews with local residents as well as interpreting maps and aerial photos to assess forest conditions and potential (Mattson 1995).

The conducted interviews focused on both the general and specific Sámi knowledge of the birch forests and their environmental conditions such as healthy stands, decline and damage in vegetation. In addition, the precise terminology in the Sámi language related to birch was recorded. All Sámi land-use practices are managed practically and spatially within "báiki", the nuclear family, and "siida", the spatial, political and socio-economic unit of the extended kinship system (Helander 1996a). Moreover, gender relations have had an influence on equity in land-use practices and management (Aikio 1990). In this respect, the use of birch is also directly tied into the socio-spatial system by providing materials and fuel for running a household and related activities, traveling on land, water or ice and in hunting, trapping, fishing and reindeer herding.

Many Sámi experts, especially older men with a long personal background in Sámi traditional livelihoods, have understood very well the changing aspects of the environment in their land-use area and even beyond in some neighboring regions. They stated that the amount of birch forests in Ohcejohka has declined over the last 50 years. This is illustrated by the Sámi concept of "vuopmi" which describes especially forests with big, old trees, often growing fairly densely in river valleys. In 2001, for example, there was no "Geavovuopmi" anymore; this place name refers to the well-known "Geavvu Valley Forest" in Ohcejohka. Today, a hiker can cut across this valley wherever she or he pleases without running into dense birch copses. This was not possible prior to the *Epirrita autumnata* epidemic of the 1960s which destroyed many birch trees (cf. Chaps. 9 and 12). To highlight this environmental change, one Sámi expert mentioned that he skied there in 1947 and tried to make fire on the snow with felled trees, but it would not start. Normally, one could easily start a fire during the winter even with green wood; however, even then the wood was probably damaged by *Epirrita autumnata* and had become useless. After the 1960s, the expert noticed that these dead trees would not burn easily at all.

The only "vuomit" (plural of "vuopmi") that still exist in Ohcejohka are in the valleys of Veahčajohka (Vetsikko) and Ohcejohka; however, forests have declined there, too. Smaller copses with large numbers of birch such as in river valleys, called "leahki" (= valley), and on elevated terrain between river tributaries, "skáidi" or "maras", are identified by "vuovdi" (= grove) or "soahkebohttut" (= birch copses) to distinguish them from "vuopmi". The combination of "vuopmi" (= woods or forests) and "čáhci" (= water) is the most important physical factor for locating human settlement in Sápmi. Many "vuomit" in Ohcejohka have now changed into "duottar" (= treeless tundra) after the herbivore epidemic of the 1960s. This event was an extreme ecological catastrophe that has had many long-term effects that the Sámi still see and feel today.

In Ohcejohka, the increased growth and northerly expansion of pine trees have been very noticeable in the timberline forests, enticed by various plantation programs of the Finnish forest administration between the 1930s and 1970s. Local people do not value pine as much as birch. Still, pine is taken as timber for building and also for making boats such as the long and narrow river boats suited for the currents of the local rivers such as the Deatnu and Ohcejohka, also on the Norwegian side.

The need for and the use of firewood have considerably declined in volume because the expanding modern infrastructure has facilitated the import of oil, gas and electricity for heating. Many traditional wood-felling areas are no longer used. They are now decaying and grown over with rather dense and twisted small birch because there is not enough light for the growth of new, stronger and taller birch. All Sámi experts stressed that firewood forests require continued, diligent management to provide for proper growth and guarantee sustainable use.

The Sámi interviewed in this project expressed quite strongly that all areas within their reach have always been in use and that they do not know or have not seen any place that is not part of their land-use practices. Areas might be left idle or fallow for some time; however, they are always part of their holistic perception of land use.

Traditionally, each family or kinship unit had their own territory, areas for different needs such as felling of firewood, fishing, picking berries (cloudberry in particular), mushrooms, snaring of ptarmigan using birch copses and twigs as guides, hunting (especially during the snaring period in late winter), reindeer herding and other activities. For obvious practical reasons, grass sod cabins whose inner frame is made of birch wood were located near birch copses and a river or lake where ptarmigan could be snared. These places were used also during fishing and reindeer herding activities. Snaring territories were quite extensive and followed the distribution range of both ptarmigan and birch. Ptarmigan snaring, salmon fishing (cf. the tripod weir system in the Deatnu), reindeer herding, hunting, arts and crafts are still practiced in Sápmi. All these activities are very much dependent on the mountain birch.

18.3 Knowledge and Values: The Meaning and Use of Mountain Birch

Sámi people still hold their inherited ways of thinking, that is the holistic understanding of life and nature which requires intensive observing, studying, understanding and knowing the physical environment before any action can be taken, even, for example, such seemingly minute tasks as felling trees. Helander (1996b, p. 1) writes, "…when dealing with sustainability from the Sami point of view, we are dealing with a holistic issue. Thus it is crucial to take into account that the concept of the environment consists of several elements such as ecological, cultural, social and linguistic factors. These elements make up the whole and must therefore be seen as one single entity." Helander (1996a,b) and also Kalstad (1996, 1997) accept that contacts with other peoples, modernization and globalization have forced the Sámi to adopt values and ways foreign to them.

It is argued that modern Sámi institutions and authorities and the political and educational elite are now in partnership with their former colonial establishment encompassing a living duality across cultural and linguistic lines. In fact, we suggest that the Sámi as other aboriginal peoples around the world are co-opted into external systems as expressed through co-management regimes to "negotiate and administer" the utilization of natural resources on "common property" or "public lands" (cf. Kalstad 1997). This interpretation of development forced upon them by the outside is much debated if one considers also the open and free flow of ideas and goods across cultural boundaries having an impact internally and externally – nobody lives in isolation. However, this issue is a matter of power distribution and relation and how power is used in asymmetric situations not only in resource management but also in science and research (Keskitalo 1994). In this context, the use of birch wood is only one of the many elements of both the human and physical environment in which Sámi intend to function holistically.

18.3.1 Birch Firewood: Securing Heat and Warmth

In Ohcejohka, all Sámi interviewed used mountain birch as firewood and stated that birch is always better than pine, even dry dead pine, "soarvi", which is used sometimes as kindling to start a fire. All interviewees' households had wood stoves and most of them also an open fireplace; some used mainly wood instead of oil or electricity for their central heating system.

In order to protect the continuation of the use of mountain birch, firewood lots or "homestead birch forests" have to be looked after by applying thoughtful management practices to secure fuel and material. These forest resources have been utilized for centuries under an ancient and precise model of actions. Under this model, various separate areas are used in temporal cycles, some shorter, 10 to 20 years, some longer, up to 100 or more years. The length of the cycle depends on the substantive growth of birch, types of topography, soil quality and climate conditions in that specific area. These intervals also assume the availability of other wooded areas as a substitute resource. The rotating pattern reduces the pressures put on these essential firewood lots.

The very first step in the assessment is which trees are to be left standing for future use. They are invariably the most healthy, straight, beautiful trees with no indication of disease or physical damage. Furthermore, this decision rests also on the environmental conditions and the layout of the landscape which might require that certain trees are left to grow and thus protect animals, plants and soil against wind, snow and ice, water, erosion, sun exposure and other impacts. The trees that are deemed to be left standing need optimal growth conditions such as light and nutrition but also the company of neighboring trees which provide support and protection. Moreover, all birch trees should never be cut down in a given area at the same time. Once the selection of the trees to be felled is made, the old, sick, damaged, crooked ones are taken first. Sometimes only branches are cut to obtain more air and space for the surrounding trees. Of course, the best quality for firewood comes from healthy, straight, relatively thick trees, and preferred wood is from richer birch forest types (see Chap. 16).

Other defining factors that contribute to the quality of firewood are the time of felling during the moon and annual cycle (i.e. before mid-summer) and the process of drying, leaving freshly leafed branches to pull the sap from the tree trunk. In the valleys of Ohcejohka and Deatnu, traditional early summer felling without cutting limbs is still being practiced. During the summer season, it is very important to cut trees at the right time, which is during the full moon or when it begins to wane. These felled trees will not rot, thus providing firewood of prime quality. Following the lunar cycle, felling in early summer also encourages young growth of birch to start at the proper time without impediment. Felling for firewood is also done during the autumn after the leaves have fallen off the trees. The wood quality for burning is also deemed good at that time.

In the autumn before snowfall, the limbs are cut and the trunks are piled up for further drying and easy locating into a "soahttu", like the poles of a conical tent. The "soahttu" is preferably placed on a hillock with rocky ground where water drains easily without being absorbed by the trunks. Fresh or green birch also burns well during wintertime (cf. Chap. 16). Even in March birch draws much moisture from the soil and does not burn as well as the wood obtained during winter. Depending on the location of the forest lots and their distance to the homesteads, trunks are taken there once a full snow cover makes transportation possible and easier. They are then stacked in vertical piles, "soahttu", depending on how long the trunks are to be left, before sawing and splitting. The "soahttu" is used for longer periods of storage.

After a period of 20 to 100 years, these woods will produce high-quality firewood, making it also available to the following generations, a long-term projection which always has been part of Sámi philosophy. This circumstance makes it obvious that large areas are needed so that decisions can be made based on the knowledge of the best conditions for the forests should firewood be needed continuously. In this model, reserve areas are also necessary to cope with damages or disasters caused by natural processes, or if a person for reasons of illness or age was incapable of felling under these strict rules of local management.

The amount of dried firewood should usually be enough to last a household for the whole heating season; in fact, this can be all year-round. Today, more and more households buy the necessary firewood in trunks to be cut and split, or even prepared wood already split and delivered as bundles in sacks. During the warm summer season, heating does not require so much energy; then smaller branches and remaining wood scraps are very suitable to burn. This way all available wood is utilized optimally.

Sawing and splitting wood are done mostly during the winter months right into late winter while the wood is still frozen. The best drying seasons for birch wood are late winter and all of summer. Once the firewood is dry, it maintains its burning quality for many years if stored properly. Some interviewees said, in fact, forever if it is stored well under a roof or in a woodshed with proper ventilation.

Certain areas are protected and excluded from taking firewood, such as places close to water springs where wood copses are left standing. Also along the shorelines of rivers such as the Deatnu, birches are left as icebreakers. Such practices protect the trees themselves, but also provide protective habitats for birds, rabbits and many other animals. Another aspect is that birch forests are spiritual or holy places, which, as some Sámi believe, are inhabited by spirits (trolls and gremlins alike). Trees are also imbued with spirits. Furthermore, if in a certain area it is deemed that the underbrush vegetation or lichens cannot sustain the impact of firewood felling, then it is decided to avoid trampling and leave the trees standing. Everybody, including children, is taught to stick to established trails and not to wander off into the forest to avoid damage.

Generally, wood taken from dense forests does not provide the expected heating energy compared to trees that have grown under conditions with more light, air and space. Wood taken from areas close to or at the edge of open and treeless mountains, "vađđa", burns much hotter. Old mountain birch trees burn as well as younger ones if they are processed in the proper way described above. Straight trees or trunks, "riktes", are easier to handle, cut and split; they contain plenty of energy, burn hot and are the prime firewood. Mountain birch has a short growing season, thus its fibers develop more tightly and densely, producing higher combustion. Straight trees, mainly monocormic (cf. Chap. 1), up to 15 cm in diameter, undamaged and with white bark are of the highest quality and quite often left standing in the forest for later use.

Sámi stories also contain advice on how to treat wood. The story of the spirit *Ruoidna* (= the Lean One) provides a reflection on the knowledge of illnesses in trees caused by rotting, mold and mycelium. Cleanliness and observance are important factors in firewood production. The story advises not to take any rotten tree to the "goahti" (= homestead) because the *Ruoidna* spirit would bring "guoržžu" (= bad luck).

18.3.2 The Proper Mountain Birch Wood for Art and Handicraft

In the selection of prime firewood, many factors come to bear and are carefully considered. To identify the suitable wood that would fulfill the high requirements for art and handicraft products asks for even more detailed studies by the artist. For example, the wooden sled runner requires a natural curve, thus a tree meeting this detail needs to be found in the wide forest, a meticulous and lengthy task. Sámi still pursue this way; however, the availability of modern means to form, bend and glue wood have led artists to buy commercially produced wood and thus forfeit this time-consuming task with its physical and mental challenges.

The search for quality wood grown in a certain way is always on a person's mind whenever one is in the forest, working, trapping, fishing or looking for appropriate trees for art and handicraft. When a tree is found, maybe it is not yet tall enough, or the moon is not right, or for some reason it is not cut down, the location will be kept in mind and, perhaps, some trees around it will be felled to provide the selected tree with the optimal conditions for growth. As a rule, such trees are never cut during the "black moon" or the "new moon for the trees" which cannot be seen. It is also referred to as the "rotten moon" because wood cut during that time will rot. When the moon waxes, the tree's sap rises and when it is on the wane, the sap recedes into the roots. Therefore, trees should be felled during the last quarter of the cycle or during full moon. The best time to fell trees is between the autumn, after the leaves have fallen and the ground is frozen, and the winter month of March. Timing is crucial to attain quality.

Today, the Sámi terminology and definitions used for the moon and its cycle in relation to the birch and its use represent a mixed picture of both indigenous knowledge and European-based thinking. This became apparent through the interviews and is also confirmed by Nielsen and Nesheim (1979), who list seven different definitions of the lunar phases.

When Sámi take wood from the forest they obtain it with the reasoning: if you take something, you have to leave something behind. This way of thinking is part of the spirituality and the respect shown to other living beings and to the world in general. The habit of knocking slightly three times on the tree with axe or knife, as is also done with the marrow bone before splitting it for the delicacy inside, is clearly a remnant ceremonial gesture offering respect before using the wood. It does not symbolize the marking of property.

Other factors are noted and kept in mind, e.g. which side of the tree is exposed to the prevalent direction of wind and sun – to the south or north. To make skis from birch trunks, the south or sunny side and the north or shadowy side of a straight tree are marked because it is believed that they have different properties with respect to density and strength. Such observations and the right timing of felling will guarantee that the forest will be kept in proper conditions for new growth. The drying is very important for wood used as working material; however, much also depends upon the professional and mental skills which differ from person to person. In order to obtain high-quality material, the wood requires a slow and lengthy drying process. Properly dried wood can be stored for several years; it will get better and better with time.

Some Sámi stated that it is not possible to buy the kind of wood they need for their art and handicraft because, to establish the necessary bond between artist and the wood (= nature), it has to be searched for, processed and prepared by the artist. In fact, the selection, acquisition and artistic shaping of wood are one continuous process that should not be separated. Generally, Sámi artists do not trust commercial producers to process wood in the way they expect it should be done, although, as mentioned above, they do rely on commercial materials. Moreover, in their utmost performance, they need to know the birch tree that provides the best wood under specific environmental conditions, including wind direction and sun exposure, type of landscape, surrounding vegetation and soil, as well as how and when the tree was felled.

All these attributes contribute to the ambience of the pieces that are produced as part of the cultural expressions directly connected with the environment.

By the 1950s and 1960s, the use of birch wood for materials in construction, carpentry and in making utensils and crafts had decreased. The cultural environment, increased motorization, mechanization, infrastructure, services, and behavior and attitudes have changed under the influence of modernization and mechanization – Sámi are not excluded from these processes. As for other developed peoples and nations, modern infrastructure, communication and transportation, electricity and other technical amenities are available throughout Sápmi (Kalstad 1996).

Sámi knowledge of wood handicraft is now fortunately stored in archives and publications which provide encyclopedic references to the use of birch wood during historic times. In Finland, wood handicraft and art are not taught in schools, rather they are only made available to adults at the level of professional colleges such as the Sámi Educational Centre in Anár (Inari) in Finland which was founded in the early 1970s. In Norway, Sámi handicraft curricula have existed for a longer period in high schools. Most of those Sámi artisans working with birch wood have inherited and learned their skills from their parents or some other skilled person, producing intricate items of art and handicraft such as, most commonly, drinking vessels, bowls, boxes, ladles, handles and other small handy items. However, after all, the demand and thus the economic feasibility of these are limited today (cf. Chap. 16), but this may change with increased tourism (cf. Chaps 15, 23, 24). The most common larger product of application might still be the various types of sleds used behind snowmobiles nowadays.

18.4 The Human Factor: Future Management of Mountain Birch Resources

The local, indigenous experts interviewed produced a holistic view of traditional and contemporary use of birch locally. The data collected serve as an encyclopedia of Sámi cultural heritage, providing historical and contemporary information on traditional ecological knowledge, practical aspects of resource management, quality of materials, ideas and rules concerning sustainable use of the surrounding northern timberline environment. Next to environmental and economic aspects, the latter ones are not explicitly discussed here; Sámi voiced their views on the position of mountain birch in their culture, spirituality and livelihood, stressing, in their own words, that the point is that "…without birch life is empty."

The birch is an integral part of the physical environment in Sápmi. Therefore environmental conditions, volume, density and quality of wood resources are of paramount importance in supporting the Sámi in their livelihood. In addition, cultural expressions and spirituality are important elements as symbols of life.

The following quotes taken from the Sámi experts provide an insight into the intense relationship between people and mountain birch.

"… in summertime, there is such a nice smell and a sense of fresh air in the birch forest; it invites me to halt and stay";
"… life would be very cold and uncomfortable without birch";
"… and without birch…the environment would turn into tundra…";
"… when I was looking for burls on birch trees in the forest, I realized that each birch had its own individual spirit…";
"… it feels so pleasant and refreshing to wander into a birch forest;…a pine forest is so dry, birch gives full moisture – a sense of full life…".

These comments show the importance of mountain birch not only as energy to heat houses and to let people exercise physically, but also as a source of personal mental health and spirituality, providing a focus for much needed refreshing contemplation. In fact, the birch is sensed to be the means to ascertain cultural traditions through physical practice, storytelling, language, taxonomy, nomenclature and terminology. Furthermore, working with birch continues the richness of ecological knowledge through applying environmental observation of changes that occur in nature and with animals and plants. All these aspects contribute to the cultural and socio-economic well-being of people in their specific environments if they are practiced properly.

Sámi realize that there are increasing external but also internal changes and pressures to which northern peoples and environments are exposed. Certainly, the local population sees the continuing use of the mountain birch in the northern timberline forests for both firewood and wood products as very important because costs for heating oil and electricity fluctuate considerably depending on the availability on the global market. Therefore, issues of ownership, access, utilization and management are at the forefront of internal and public debate. It is generally understood that a structure of rules needs to be negotiated to manage the birch mountain forests as a resource.

The Sámi on the Finnish side of Sápmi pointed to the omnipresent role of Metsähallitus, representing the Finnish national interests in forest resources, as an interference in local affairs. It was agreed that its role is in need of redefinition, i.e. the influence of Metsähallitus on forestry management should be decreased. This public institution has now become a commercial enterprise with the assumption of making a profit to justify its existence. The expanding commercialization of birch as well as intense tourist activities are a threat to the continuing integrity of mountain birch use by Sámi. New infrastructures and economic developments such as roads, industrial forestry, hydroelectric power production and mining need to be planned very carefully, preceded by impact assessment studies focusing on environmental, socio-economic and cultural aspects (cf. Chaps. 16, 23, 24).

The Sámi views on these matters were clearly expressed in the interviews:

"We need to live in observance of the traditional rules, obtain more knowledge and skills, train our children. Use paths and avoid trampling all over. We have gone too far, too fast with the mainstream in a heavily competitive and competing world. We need to stop, think and go back to our traditional knowledge."
"…I wish that there was never a time again when the electric power company built the lines here….I also wish that I could keep my relationship with the birch…."
"Sámi people are the real protectors of their environment, not the authorities."
"Values and regulations by others have influenced us. Their regulations stress protection and conservation, but it is something else they lead to. They cause competition avoiding to take responsibility for the environment."

In this context, the value of traditional knowledge has to be recognized and enhanced by its teaching in schools and by its acceptance as part of planning and policy making for the utilization of specific resources such as the mountain birch forests.

18.5 Outlook: Prospects and Policy Recommendations

The question still remains: how can management and sustainability of mountain birch resources be achieved under current socio-economic and political circumstances? Reflecting on such phrases as "…without birch life is empty;…we cannot be without the birch" or "…the birch is closest to us Sámi", what can be done to have life continued to be filled with birch? It is accepted that regulations including management plans are needed because, in fact, more people, both locally and from the outside, have shown different interests in the same resource in the same place at the same time. According to the statements given in the interviews, local people, be they Sámi, Finns or others, need to be involved in the decision-making process concerning how local resources are to be exploited under current conditions (cf. Chap. 23). This would also allow projections for future use (cf. Nystø 1998). Some members of the younger generation have no longer been raised in the traditional Sámi society and its values; some moved away from Sápmi to centers in Finland, Norway and Sweden, and are thus not concerned with obtaining firewood for their households on a daily basis. Therefore the distance between these people and the environment has mentally and physically increased for them.

Because the mountain birch is a crucial element of the environment and an important factor in local people's life and knowledge, management proposals and policies have to derive from people living within the birch forests and not from civil servants' office desks from a distance. This type of management can be achieved through extended local guidance on and control over the various types of land users in forestry, sports fishing and hunting, tourism and recreation (i.e. cabin owners), such as through the Sámi siida system, Sámi parliaments or local administrations and associations. For example, programs setting aside "wilderness" areas for nature protection and conservation need to accept and integrate local traditional ecological knowledge, expertise and land-use practices. Both local knowledge and management models deserve inclusion in school curricula so as not to lose a sense of place for pupils growing up in the northern environment. Furthermore, knowledge and skills have to be acquired by each generation, in fact, a kind of re-education in the proper use of resources. As one Sámi said, "...not all the old time hunters were skillful in grouse trapping; if they were not careful enough to see which twig they should cut and use for a ptarmigan trap, disaster would occur."

People do generally agree that restrictions are needed today. The times have changed and the old, timeworn models do not always apply anymore; however, they are still valid in their own ways (cf. Chaps. 23–25). Modern society is guided more by money and material items than by nature and its signals. In the eyes of many Sámi, these conditions and attitudes cause much irreparable damage to the natural environment. To come back to the birch: nowadays, people get into the habit of felling birch for firewood during any season, e.g. in late winter, April and May, when snow is hard. Then it is easy to travel by snowmobile and transport the trunks immediately home, disregarding the necessary drying process and risking acquiring poor quality wood for reasons of expediency and convenience. Wood felled in late winter and spring will still burn; however, the wood is of poor quality because the sap has already risen and this makes it heavy and wet. Trunks left in deep snow will absorb even more moisture, contributing to inefficient combustion.

The continuation of sustainable use of mountain birch resources is extremely important locally. The Sámi feel that "...birch gives so much: warmth, protection, pleasure, company, medicine. It is beautiful and gives material for many things, green leaves and good smells". The symbolism and the factual reality as sources of energy which the birch, "soahki", holds in Sámi culture and livelihood need to be maintained and secured if local communities are to make sense of their existence in their very own environment.

Acknowledgments. The study was funded by the European Union Research Commission under the project HIBECO 2000–2003. The authors are grateful to the local experts and colleagues in Workpackage 1 (Hamburg University, Germany) led by Dietbert Thannheiser. The Finnish Forest Research Institute (Vantaa, Finland) granted permission to republish large sections from our article "Living at the timberline: the Sámi and the mountain birch forests in northernmost Europe" (Aikio and Müller-Wille 2002), letter from Kari Mielikäinen, 21 October 2002. The authors thank Linna Weber Müller-Wille for editing the English text.

References

Aikio MS (1990) The changing role of women in Sámi society. In: Müller-Wille L (ed) Social change and space. Indigenous nations and ethnic communities in Canada and Finland. Minor in Northern Studies Program, McGill University, Montreal, pp 13–17

Aikio MS (1998) Tourism in the north and Sami culture. Juridica Lapponica 19:87–92

Aikio MS, Müller-Wille L (2002) Living at the timberline: the Sámi and the mountain birch forests in northernmost Europe. Finn For Res Inst Res Pap 862:40–56

Baer L-A (1996) Boreal forest dwellers: the Saami in Sweden. Unasylva 186(47):16–21

Cox CB, Moore PD (1993) Biogeography. An ecological and evolutionary approach. Blackwell, Oxford

Helander E (1992) Sámi knowledge – subjective opinion or science? Diehtogiisá 1(92): 3–4

Helander E (1993) The role of Sami traditions in sustainable development. In: Käkönen J (ed) Politics and sustainable growth in the Arctic. Aldershot, Dartmouth, pp 67–79

Helander E (1996a) Development, knowledge and Sami reindeer herding. In: Jacobsen B (ed) Cultural and social research in Greenland 95/96. Essays in Honour of Robert Petersen. Ilisimatusarfik/Atuakkiorfik, Nuuk, pp 107–118

Helander E (1996b) Sustainability in the Sami area: the X-file factor. In: Helander E (ed) Awakened voice. The return of Sami knowledge. Dieđut 4:1–6

Helander E (1999) Traditional Sámi knowledge. Arctic Centre Rep 26:25–27

Hustich I (1946) Lappland lever (Lapland lives) (in Swedish). Holger Schildt, Helsingfors

Hustich I (1979) Ecological concepts and biogeographical zonation in the north: the need for a generally accepted terminology. Holarct Ecol 2:208–217

Kalstad JK Hætta (1996) The modern challenge facing knowledge in Sami subsistence. In: Helander E (ed) Awakened voice. The return of Sami knowledge. Dieđut 4:21–30

Kalstad JK Hætta (1997) Aspects of managing renewable resources in Sami areas in Norway. In: Gaski H (ed) Sami culture in a new era. The Norwegian Sami experience. Davvi Girji OS, Kárášjohka, pp 109–126

Kankaanpää S, Tasanen T, Sutinen M-L (eds) (1999) Sustainable development in northern timberline forests. Finn For Res Inst Res Pap 734:1–187

Kankaanpää S, Müller-Wille L, Susiluoto P, Sutinen M-L (eds) (2002) Northern timberline forests: environmental and socio-economic issues and concerns. Finn For Res Inst Res Pap 862:1–132

Keskitalo A-I (1994) Research as an inter-ethnic relation. Arct Centre Rep 11/Dieđut 7:7–31

Lehtinen AA (1991) The northern natures – a study of the forest question emerging within the timber-line conflict in Finland. Fennia 169:57–169

Mattson J (1995) Human impact on the timberline in the far north of Europe. Zesz Nauk Uniw Jagielloñ Pr Geogr 98:41–55

Nielsen K, Nesheim A (1979) (1932–1962) Lappisk (samisk) ordbok. [Lapp (Samish) dictionary.] Institutt for sammenlignende kulturforskning, Oslo

Nystø S-R (1998) Decision-making and priority-setting in the circumpolar North. North Rev 18:119–128

Senkpiel A, Coates K, Kleinfeld J (eds) (1998) Sustainable development in the arctic. North Rev 18:5–256

Veijola P (1998) Suomen metsänrajametsien käyttö ja suojelu (in Finnish with English abstract). [Utilization and protection of Finland’s timberline forests]. Finn For Res Inst Res Pap 692:1–171

19 Sustainable Reindeer Herding in Mountain Birch Ecosystem

K. Lempa, S. Neuvonen and H. Tømmervik

19.1 Introduction

Political and economical changes throughout the last 150 years have affected herding practices and thereby changed both the number of reindeer and their pasture quality in Finland, Sweden and Norway. In this chapter we aim to show how the interplay between ecological, historical and economical factors affects sustainability of reindeer herding in the mountain birch ecosystem. It seems that there is no unique way to put into practice socially and economically sustainable reindeer herding.

In Chapter 11, the vulnerability of pasture components to reindeer grazing is discussed as well as the response on actual reindeer density. In this chapter, the history and cultural background of reindeer herding are discussed, including the social and economical factors involved. The chapter concludes with suggestions for sustainable reindeer herding.

19.2 History

Access to the pastures in mountain birch forest is a necessity for sustainable reindeer herding, but the Sámi have not always had free access to these pastures. Both governments and local authorities have controlled the pasture availability. In the 17th century, the Swedish government simplified the taxation system of the Sámi. The tax was based on the area utilized by a Sámi community and it was paid collectively. This model favoured large-scale reindeer herding and spread rapidly over northern Sweden, northern Norway (the county of Troms and western Finnmark) and northwestern Finnish Lapland (Arell 1977; cf. Chap. 24). The Strömstad treaty in 1751 established free access for reindeer-herding Sámi in Finland, Sweden and Norway.

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

The authorities set the first limits to reindeer herding in the 1790s when the southern limit for reindeer herding was established in order to avoid conflicts between farmers and reindeer herders. The major constraint to free access to the pastures was the treaty between Russia and Sweden–Norway in 1852, which closed the Finnish/Norwegian border and restricted access to the high-quality winter pastures on the Finnish side. For some time the Sámi tried to circumvent the border closure by migrating to Finland via northernmost Sweden, but Russia closed the Finnish/Swedish border in 1889 (Hemmer 1985; Ruotsala 2002). Consequences of the border closures were far-reaching. Sámi reindeer herders in the county of Finnmark in Norway had to choose between Norway and Finland. Some Sámi stayed in Norway and they lost their winter pastures in Finland; on the other hand, Sámi reindeer herders in northwestern Finland lost their summer pastures at the Norwegian coast (Hemmer 1985). A large number of Sámi moved permanently from Norway to northern Finland (Arell 1977; Hemmer 1985; Ruotsala 2002). They brought with them the model of large-scale reindeer herding, which replaced the older mode of living, relying on more diverse sources of income: fishery, hunting, small-scale agriculture and small-scale reindeer herding (Arell 1977; cf. Chap. 24).

19.3 Cultural Background

In Sweden, reindeer husbandry is a privilege of the Sámi, whereas in Norway there are some non-Sámi reindeer herders. In Finland, both Sámi and local Finns have the right to keep reindeer. Most Sámi villages in Norway and Sweden follow the traditional pasture rotation (cf. Chap. 11). Summer pasture areas in the county of Finnmark, in northernmost Norway, are in the coastal areas and islands close to the mainland, whereas more southern Sámi villages use both mountain and coastal heaths as summer pastures. In Sweden, mountain Sámi villages have the summer pastures above the tree line; the forest Sámi villages use bogs as summer pastures (Skjenneberg and Slagsvold 1968; Chap. 24).

The traditional economical unit of mountain Sámi was "siida" (Chap. 18), an autonomous herding unit connected to the tribal system. Siida consists of one or more families which followed their reindeer year-round, and thus herders can continuously control reindeer welfare and pasture conditions (Anonymous 1966). Finnish authorities wanted to control relationships of reindeer herding with other modes of land use, e.g. forestry and mining. Therefore, every reindeer owner was forced to participate in a herding co-operative (paliskunta in Finnish) in 1899. This was originally a loose association for round-ups in forest areas of Lapland (Ruotsala 2002), and was a good solution for forest Sámi having small reindeer herds and rather sedentary ways of living. For migrating mountain Sámi, however, the solution was not the best possible, since the paliskunta system limited migrations and effective pasture rotation.

The rotation practises (cf. Chap. 11) vary in different parts of reindeer herding areas. In northern Norway, the district-specific mean summer pasture period is 128 days, ranging from 55 to 178 days (Ims and Kosmo 2001). The summer pasture period in the Norrbotten mountain area in Sweden is on average 97 days, but the variation is large, ranging from 35 to 215 days (Anonymous 1966). In Finland, small-scale pasture rotation is practised in four co-operative herding districts in the mountain birch zone. The timing of pasture rotation in northernmost Finland follows quite closely that practised in northern Norway. Reindeer are moved to their summer pastures at the time of snow smelt and they come back to the winter pastures in September–October (Veijo Tervonen, pers. comm.). In general, the winter pastures are in areas where snow conditions are favourable, most often in forested areas, but in some cases even at the coast, e.g. in the county of Nordland, northern Norway.

19.4 Social and Economical Factors

Predators are considered to regulate reindeer populations (Bergerud and Ballard 1998) and locally they can cause much damage (Pedersen et al. 1999). Since the 1950s, herders have reduced the number of large predators, i.e. bear, wolf, wolverine, lynx and eagles (Hemmer 1985; Riseth 2000). In the 1990s, EU membership in Finland and Sweden brought about directives protecting large predators. The number of large mammalian predators has increased in the 1990s (Reindeer Herders' Association, Finland see http://www.paliskunnat.fi/yhdistys). The herders are compensated for losses by predators, and such compensation is relatively generous. However, in many cases, compensation is considered insufficient (Ruotsala 2002). For young reindeer owners, who are developing their herds, a random attack can cause damage that is not easily compensated, since the government compensates for the animal losses but not the time and labour allocated to the herd development. On the other hand, predation compensation may be relatively beneficial for established owners who have a large herd. A single predation event does not usually seriously damage a single large herd, and predation compensations provide a stable cash flow, which contributes to maintenance of a large herd.

The EU membership of Finland and Sweden has affected herding practices. Before then, each roundup area used to have its own slaughterhouse. Within the EU, however, reindeer were collected in roundup areas and transported by trucks to high-quality slaughterhouses. Moreover, in Finland, the subsidies are directed to reindeer owners having more than 70 living animals (Ministry of Agriculture, http://www.mmm.fi/tuet/luontaiselinkeinot/porotalous). This favours large-scale reindeer herding and reduces the number of reindeer herders (Hukkinen et al. 2002). On the other hand, those families, for whom reindeer is an important but not the only source of income, will suffer from the subsidy policy (Ruotsala 2002).

A large economical change in reindeer herding started in the 1950s. Motorization made herding practises more efficient and reindeer vaccination reduced mortality considerably. These were the tools for a more efficient pasture use and a higher productivity. Modern methods were more costly than the traditional ones and a larger herd size was required for profitable reindeer management (Riseth 2000). Furthermore, competition with other land users, foresters, farmers, mining and electric companies, tourism companies and the military, has limited pasture use in northern Fennoscandia. In Norway and Sweden, because of a more migratory ranging model, the Sámi have had problems with other land users (e.g. Vistnes and Nellemann 1999, 2000), which, however, can also provide a supplementary source of income for Sámi communities.

19.5 Suggestions

Sustainable reindeer herding in mountain birch forest requires lower reindeer density than that currently found in many areas (Helle 2001). Pasture rotation alone is not an efficient tool for sustainable pasture management. For instance, in western Finnmark, reindeer herds with pasture rotation are observed to overgraze their food sources (cf. Chap. 17; Tömmervik et al. 2004). Therefore, pasture rotation and controlled reduction of grazing pressure should be applied simultaneously.

Impacts of any modern activities should be evaluated carefully beforehand. For instance, new electric power lines will reduce calving and spring pasture area to some extent and have local importance in small coastal reindeer herding districts (Nellemann 1996; Vistnes and Nellemann 1999) On the other hand, other forms of land use can be considered as additional sources of living rather than competitors. Historically, this has been the strategy in many reindeer herding communities in Fennoscandia (Arell 1977; Hemmer 1985; Ruotsala 2002).

The mountain birch zone is an unpredictable environment. A sustainable model for reindeer herding should diminish losses caused by extreme conditions of the zone. The model can reduce the negative effects of unpredictability by ranching and supplementary feeding. A part of the traditional knowledge of reindeer management may be disappearing with this transformation of herding from pastoralism to proto-ranching (Ingold 1980).

Acknowledgements. The first author appreciates the discussions with Otso Suominen and Helena Ruotsala.

References

Anonymous (1966) Renbetesmarkerna. Betänkande avgivet av renbetsmarkutredningen (in Swedish). Statens Offentliga Utredningar 22:1–273

Arell N (1977) Rennomadismen i Torne Lappmark-markanvändning under kolonisaionsepoken i fr.a. Enontekis socken (in Swedish). Acta Reg Soc Skytt 17:1–336

Bergerud AT, Ballard WB (1998) Wolf predation on caribou: the Nelchina herd case – a different interpretation. J Wildl Manage 52:344–357

Helle T (2001) Mountain birch forests and reindeer husbandry. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris, Parthenon, New York, pp 279–291

Hemmer I (1985) Entwicklung und Struktur der Rentierwirtschaft in Finnmark und Troms (Nordnorwegen). Bamberger Wirtschaftsgeographische Arbeiten Heft 1 (in German). Universität Bamberg, Bamberg, pp 1–347

Hukkinen A, Jääskö O, Laakso A, Müller-Wille L, Raitio K (2002) Poromiehet puhuvat. Poronhoidon ongelmat, ratkaisumahdollisuudet ja tutkimustarpeet Suomen Lapissa poromiesten näkökulmasta (in Finnish). Technology, Society, Environment 1/2002. Helsinki University of Technology Laboratory of Environmental Protection, Espoo, pp 1–36

Ims AA, Kosmo AJ (2001) Høyeste reintall for distriktene i Vest-Finnmark (in Norwegian). Reindriftsforvaltningen, Alta, pp 1–153

Ingold T (1980) Hunters, pastoralists and ranchers. Reindeer economies and their transformations. Cambridge University Press, Cambridge

Nellemann C (1996) Terrain selection by reindeer in late winter in central Norway. Arctic 49:339–347

Pedersen VA, Linnell JDC, Andersen R, Andrén H, Lindén M, Segerstöm P (1999) Winter lynx *Lynx lynx* predation on semi-domesticated reindeer *Rangifer tarandus* in northern Sweden. Wildl Biol 5:203–211

Riseth JÅ (2000) Sámi reindeer management under technological change 1960–1990: implications for common-pool resource use under various natural and institutional conditions. A comparative analysis of regional development paths in west Finnmark, north Trøndelag, and south Trøndelag/Hedmark, Norway. Department of Economics and Social Sciences, Agricultural University of Norway, Ås

Ruotsala H (2002) Muuttuvat palkiset (in Finnish). Suomen Muinaismuistoyhdistys, Helsinki

Skjenneberg S, Slagsvold L (1968) Reindriften og dens naturgrunnlag (in Norwegian). Universitetsforlaget, Oslo

Tømmervik H, Johansen B, Tombre I, Thannheiser D, Høgda KA, Gaare E, Wielgolaski FE (2004) Vegetation changes in the Nordic mountain birch forest: the influence of grazing and climate change. Arct Antarct Alpine Res 36(2) (in press)

Vistnes I, Nellemann C (1999) Tap av kalvingsland som föge av forstyrrelse fra hyttefelt og kraftlinjer (in Norwegian). Reindriftsnytt-BoazodoalluúoDDasat 33:15–19

Vistnes I, Nellemann C (2000) Når mennesker forstyrrer dyr – En systematisering av forstyrrelseseffekter (in Norwegian). Reindriftsnytt-BoazodoalluúoDDasat 34:28–32

20 Competition Over Nature, Space, Resources and Management in the Mountain Birch Forest Ecosystem in Northernmost Fennoscandia: A Synthesis

D. Thannheiser, L. Müller-Wille, F.E. Wielgolaski
and K.-D. Meier

Since deglaciation, human populations have lived in and used resources in arctic and subarctic terrestrial ecosystems. Especially the mountain birch (*Betula pubescens* ssp. *czerepanovii*) forest ecosystem of northernmost Fennoscandia and coastal areas of the European North Atlantic arch has seen a variety of human adaptations to this physical environment over the last few millennia. Local populations in the North Atlantic rimland – from east to west, the aboriginal Sámi, immigrant Finnish, Scandinavian, Celtic (Scotland) settlers, and to a lesser degree Icelanders and Inuit (Kalaallit Nunaat/Greenland) – along with herded and domestic animals, such as reindeer and sheep, have utilized these northern forest environments, intensively competing over specific resources through hunting, fishing, gathering, reindeer herding, hay–dairy agriculture, forestry, material production and, finally, modern industrial activities including tourism and recreation. Moreover, nature at the timberline, the forests and in particular those dominated by birch, also holds intrinsic cultural and spiritual values that are inherent elements of northern peoples' quality of life (see Chap. 18). It is this varied human interest and its impact on the mountain birch forests that are the focus of the studies in this section.

There exists an intricate relationship between humans and mountain birch forests expressed by detailed environmental knowledge based on the historic and current use of birch by both local residents and external users (see Chaps. 16 and 18). In the early 21st century, the socio-economic relationships with these forest resources and the cultural values given to them are changing rapidly, locally and globally, within the context of increased competition over space and resources, expanding modernization, political and economic globalization (see Chaps. 19, 23, 24) and environmental conditions (see Chap. 17). Thus, for example, the recent northern extension of the European Union with its administrative and political apparatus is just one example of impact on

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

rural development and resource management of forests that influence the production and yield of wood and other products to the benefit of local communities. The future levels of quality of life for these populations and the management of local living resources are thus of paramount importance for the continuation of human occupancy and land use (see Chaps. 18 and 19), future sustainability (see Chap. 16 and chapters in Sect. 4) and biodiversity of the mountain birch ecosystem (see Chaps. 14 and 17).

The studies included in Section 3 (Chaps. 14–19) address and assess some of the fundamental questions on the sustainability of the rapidly increasing competition over the use of the mountain birch ecosystem in northernmost Fennoscandia. By trying to understand both environmental and human mechanisms at work, it is assumed that the viability of small northern communities and their standard of living are enhanced through the expansion of local control (Chap. 18) and the application of appropriate management regimes of living resources (see Sect. 4) such as the mountain birch forests – vital elements of continued human occupancy of ecologically sound landscapes in northernmost Europe (see Chaps. 15 and 17).

Earlier research on the mountain birch ecosystem, focusing on the human dimension, has been scarce and mainly descriptive. There has been a lack of analytical and systematic approaches to the economic and political aspects of

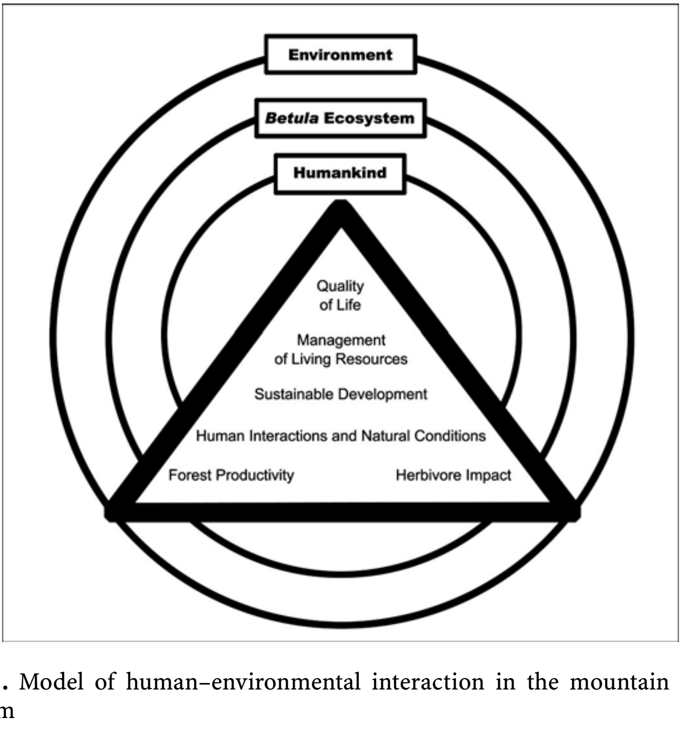


Fig. 20.1. Model of human–environmental interaction in the mountain birch forest ecosystem

birch utilization by humans and animals (mainly by reindeer and sheep) by using the detailed taxonomic field and laboratory data that are available in many cases. The current studies presented in these syntheses provide basic groundwork for the interpretation of the intense human–environmental interactions in this delicate ecosystem (Fig. 20.1).

The natural mountain birch forest on the Finnmarksvidda with its plant communities on dry and wet grounds is a climax vegetation, but changing dynamically. The composition of the herb, moss and lichen layers has changed during the last decades due to anthropo-zoogenic influences (see Chap. 17). The increase in the reindeer population is reflected especially negatively in the crowberry (*Empetrum*) birch forest grazed by these animals from autumn to spring. During the last decades, the fruticose lichens, serving as winter forage for the reindeer, did not regenerate; instead crustose lichens, which are not eaten, expanded (Fig. 20.2). The regeneration of the fruticose lichens does not take place as a consequence of climatic change. Higher humidity during the summer season favours the growth of grasses and mosses. The most striking characteristic of the herb layers is the advance of the vascular plant dwarf cornel (*Cornus suecica*), which is known as an indicator of a more oceanic climate (Fig. 20.3).

Based on this study (see Chap. 17), and if current climate trends continue, one may expect that young birch trees, grasses, herbs, mosses and crustose lichens will increase on the Finnmarksvidda. In the coastal region of Målselv,

Fig. 20.2. Lichen-rich *Empetrum* (crowberry) birch forest grazed by reindeer; former shrubby lichen cover has been replaced by crustose lichens. (2001)

Fig. 20.3. Abandoned camp site overgrown by dwarf cornel (*Cornus suecica*). (2001)

the composition of the herb, moss and lichen layers has also changed during the last decades due to anthropo-zoogenic impact. In both regions, the number of herbivores (including sheep at the coast) increased up to the 1990s; but since then it has been reduced, which has been reflected in the vegetation cover, at least in the Målselv region (see Chap. 17). In contrast to inland areas, the anthropo-zoogenic degradation of the birch forest vegetation diminished in the coastal region.

The mountain birch forest represents a unique plant formation in the world and its biodiversity and cultural diversity are today endangered. Its viability and sustainability in both natural and human terms need to be enhanced by allowing local management practices to continue and to maintain their proper place (see Chap. 18). Local residents, including Sámi as well as non-Sámi, have a common knowledge of the mountain birch and share traditions related to the natural environment. For the Sámi the fundamental concept of birch, 'soahki', includes an intricate vocabulary expressing both natural phenomena and the practised management of wood resources. Large-scale utilization of the mountain birch forests at the timberline is not feasible under both prevailing environmental and human conditions in the north because the limited growth does not allow expansion in economic terms (see Chap. 23). Thus reasonable and sensible regimes for continued forest use are crucial to the well-being of local communities (see Chap. 18).

The increase in human mobility through year-round recreation by hikers and campers, skiers, snowboarders, four- and two-wheeler traffic (see Chaps. 15, 16, 24) and even dog teams constitutes a far more rapidly expanding competition in the mountain birch forest . Such activities, although today considerably restricted and confined by law to specific corridors, cause anthropogenic disturbances in the form of vegetation depletion and soil erosion in this sensitive ecosystem. Northern natural areas are an attractive destination for the increasingly lucrative ecotourism trade. This brings larger numbers of people into direct contact with delicate northern habitats. It is established that skiing, camping, hiking and related recreational activities have locally detrimental effects on subarctic/subalpine, alpine and boreal vegetation and soils. There is the potential for serious degradation of such landscapes. Possibilities for restoration of these degraded biotopes are not fully understood due to limited experimentation in the mountain birch forests. However, studies of the field- and bottom-vegetation layers in low-alpine regions are expected often to be representative also for the Nordic mountain birch region, particularly if the elevation of the forest is increased in the future, e.g. by climate change (cf. Chaps. 1 and 21). Tourists easily impact and can destroy vegetation along trails by hiking (see Chap. 14). Furthermore, reindeer graze on mountain birch seedlings and basal sprouts which may delay the regeneration of trees. This is clearly seen in reindeer management in comparison with grazed and non-grazed areas (cf. Chap. 11). These trends clearly warrant suggestions for the development of management schemes and practices that will be able to cope with these changing environmental and socio-economic conditions if reindeer herding is to be sustainable (see Chap. 19). However, it is apparent that a continuing increase in people frequenting these areas intensely will cause more vegetation and soil degradation, making it practically paramount to restrict the numbers of tourists in those areas that are hardest hit (see Chap. 15).

The economic limits and possibilities for sustainable utilization of the mountain birch forests depend on a number of factors and imponderabilities (see Chap. 16). The success of birch utilization is clearly guided by the interplay between nature, i.e. the supply provided by growth (reproduction, age structure and quality) and amount of biomass, and the human needs for extraction of materials influenced by demand and monetary expenses, as well as returns and geographic factors such as location and spatial infrastructure. Furthermore, there is, at times, competition over this resource between humans and reindeer, the latter also being an important contributing element to the socio-economic well-being of their owners. Any management plans (see Chap. 19) have to take into consideration these factors in a holistic approach in order to arrive at policies whose goals are the sustainable use of the mountain birch forests without undercutting the viability of this resource. The analysis of the existing birch wood economy (see Chap. 16) indicates that today monetary returns are rather minute. With respect to bioenergy production as fuelwood, economic returns are higher in some of the areas studied (but see also Chap. 23). This return might be even higher for birch wood if energy prices increase; however, local communities need to adjust to this encompassing condition and practice of birch utilization in a sustainable manner suitable to their socio-economic and cultural expectations.

It must be recognized that there are limits to competition in resource development of environmentally sensitive areas if appropriate levels of both biodiversity and sustainability are to be achieved for the well-being and quality of life of local populations. Still, it is evident from the present studies that vegetation types influenced and/or introduced by anthropo- and zoogenic activities need to be secured in order to protect species as well as biodiversity in the broadest sense. Therefore, the challenge exists to reconcile the demands for both biodiversity and economic utilization based on principles of sustainability. For example, birch forest industry activity exists only in one of the project areas studied (Målselv, Norway), where it is highly compatible with the environment, providing important income and employment in this rural area (see Chap. 16). Clearly, local communities stress their right to access birch as a resource for firewood, materials for handicraft and construction versus the expanding externally based industrial and recreational interests. In some mountain birch forests, however, stronger logging than at present may be recommended for the forest culture and can also be advantageous to the accessibility for grazing animals in the forest in future (see Chaps. 16, 17, 22).

In this context, the implementation of negotiated management regimes may have a future to maintain, restore and enhance sustainable and multifunctional land-use practices in order for humans to continue to be able to access forest resources. At the same time, the biodiversity of the mountain forest ecosystem can be upheld as a viable natural and human environment – the northern cultural landscape – under arctic and subarctic conditions. To achieve this goal there has to be an increase in public awareness, fostering a sense of responsibility to preserve and develop the quality of life founded on nature-based livelihoods and resource management for the benefit of present and future northern communities, whose viability is threatened at the beginning of the 21st century.

Acknowledgements. The authors appreciate the comments and information provided by senior authors of chapters in this section (B. Forbes, A. Tolvanen, B. Solberg, M.S. Aikio, K. Lempa) as well as the linguistic editing of the English text by Linna Weber Müller-Wille.

Section 4

Modeling Dynamics of Mountain Birch Forests, Management and Future

21 Landscape-Scale Model Relating the Nordic Mountain Birch Forest Spatio-Temporal Dynamics to Various Anthropogenic Influences, Herbivory and Climate Change

A.O. GAUTESTAD, F.E. WIELGOLASKI and I. MYSTERUD

21.1 Introduction

Spatial modeling, in general, is challenged by three major aspects of system complexity. Two of these aspects are well known in contemporary systems ecology, and can be studied numerically or analytically within the context of traditional frameworks of mathematics and statistics (O'Neill et al. 1986; Cappuccino and Price 1995). The third aspect of complexity is more intricate, and involves interscale effects that cannot easily be modeled and understood from standard approaches (e.g. O'Neill and King 1998). This framework is still in large part a young scientific theory with great promises for better understanding of complex systems, i.e., it would be of great importance also for management of northern mountain birch forests.

Below we illustrate these three aspects of complexity in natural systems. W then describe the spatially explicit, dynamic HIBECO (Human Interactions with the mountain birch ECOsystem) model, where complexity becomes apparent in a practical modeling context. An application of the model to produce northern birch forest management scenarios is presented in Chapter 22.

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

21.2 Complexity Aspects in the Northern Birch Forest Ecosystem

21.2.1 Aspect 1: Challenges from Quantity of Interactions – System Complexity

One of the main considerations during the development of a model is to balance the need for a multitude of component interactions, on the one hand, against inclusion of local details of parameter variations of each component on the other. If too many interactions are included in the model, it becomes more descriptive and specific rather than analytically tractable with power for generalization. The HIBECO project takes into consideration a wide spectrum of mountain birch ecosystem components, spanning human interactions, forest productivity and herbivory (Fig. 21.1). Each of these main sec-

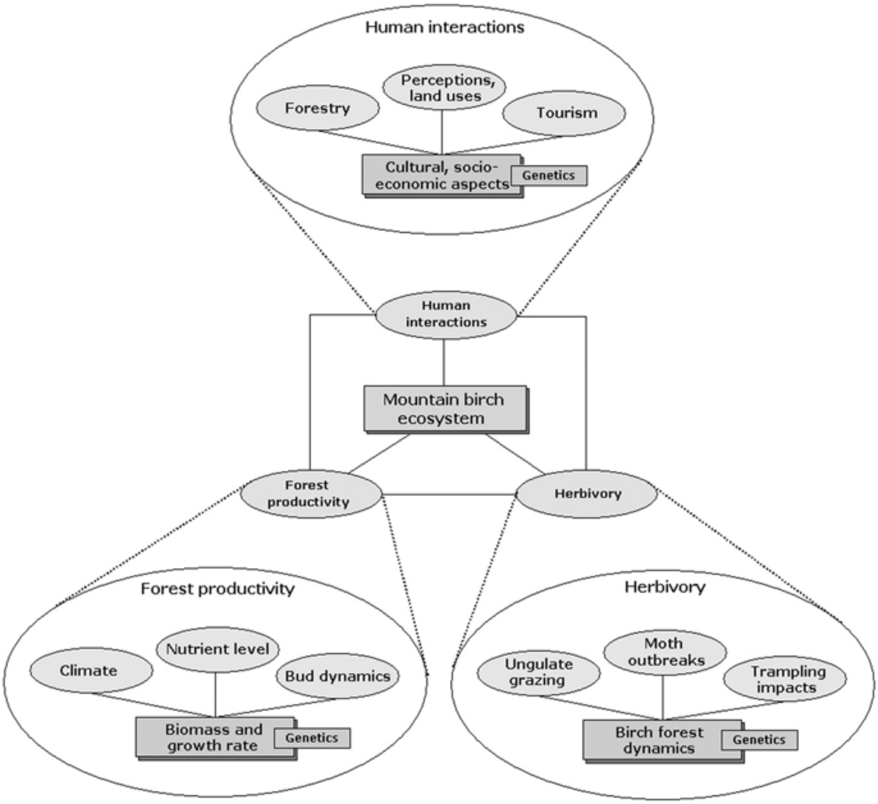


Fig. 21.1. Simplified overview of the HIBECO project, illustrating a complicated model structure with many interactions

tions represents an extensive set of processes in its own right. Further, each of these system interactions have their specific local variations. For example, age-specific parameters for mountain birch growth, survival and form (mono- vs. polycormic growth form) will vary with genetics, herbivory, local climate and edaphic conditions.

From a modeling perspective, it is always a major challenge to filter out and to balance a proper subset of specific processes and interactions at the expense of other processes. In this respect, it is important to focus on the main purpose of the current model: it is meant to be a tool to explore various scenarios for sustainable use of the mountain birch ecosystem. We have kept the model structure relatively simple, in order to focus on the specific scenarios, and complexities in that respect, which we have chosen to address in this work (see HIBECO model description below, and Chap. 22).

21.2.2 Aspect 2: Processes in Linear Superposition – Scale-Specific Spatio-Temporal Interactions

Traditionally, in spatio-temporal model terms, one often assumes that local effects can be explained by a set of local causes. In this framework, the influences appear within a given locality (represented by the “grid cell” in the HIBECO model arena, or “pixel size”) or they appear from interactions with the immediate neighborhood of a site (“surrounding cells”). However, consider the removal of mountain birch trees for firewood or handicraft material, which is a function of many factors outside the patch where the trees are actually removed: distance from roads, cabins and villages, and socio-economic factors like year- and season-dependent prices for firewood are all important parameters in order to understand the local birch patch dynamics (Fig. 21.2).

In practice, such a multi-scaled disturbance regime can in some instances be incorporated into the model as a superposition of forcing functions with a multitude of characteristic spatial and temporal ranges of influence (O’Neill et al. 1986; Shugart and Urban 1988; King 1991; Kaneko 1993). This system decomposition principle of superposition is implemented in many aspects of the HIBECO model. The principle is illustrated in Fig. 21.3, where the system consists of two scale-specific processes in superposition inside a defined area, using insect population dynamics in a mountain birch forest as an example. Process 1 is a coarse-scale “mean field” component of the dynamics, while process 2 is a more short-waved, or fine-scaled, field. These two processes also have their respective complementary “particle expressions”.

In addition to the two dispersal processes shown in Fig. 21.3, we could also expand the model with similar processes for even more fine-scaled and spatially restricted movements of, e.g., non-ballooning insect larvae, and also

Fig. 21.2. A typical mountain birch forest landscape in the subalpine subarctic ecotone, illustrating how processes influencing any given part of the mountain birch forest may belong to a multitude of space and time domains. Events in local patches (*inner circle*) are influenced by conditions and events at coarser scales (say, at the scale of the *outer circle* and far beyond), in addition to local interactions directly (local soil, snow layer and humidity conditions, etc.). This kind of influence could be due to specific events in this broadly defined neighborhood in the past, like spreading of an insect outbreak or a forest fire, or it could be due to an accumulation of events that produces an influence that spans a relatively coarse time scale. For example, consider the gradual influence from a new settlement of cabins near by, or an increased and persistent demand for firewood from towns in the region

more coarser-scaled dispersal of the moth's natural enemies like parasitoids and insect-eating birds and small mammals.

If each of these processes describing components of the moths' spatio-temporal population dynamics can be assumed (or verified) to be scale-specific, i.e. each of the components are reasonably constrained to a characteristic scale, the principle of superposition may be applied. More research is needed to clarify in more detail if this is the case for the mountain birch system, or if we need to develop an alternative framework (below) that can handle scaling complexity explicitly.

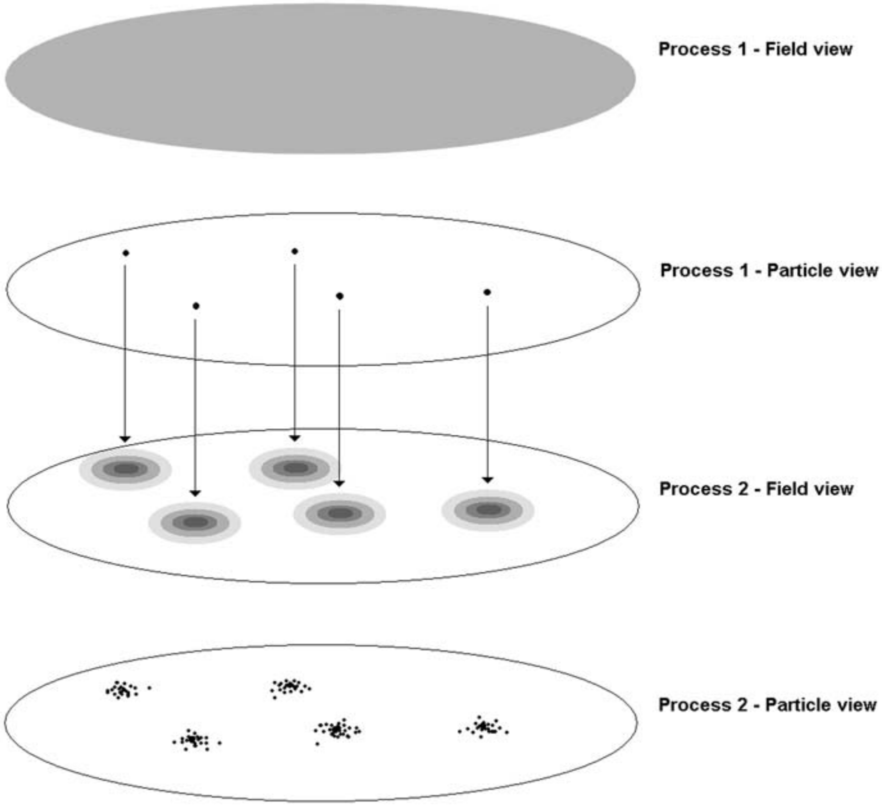


Fig. 21.3. The principle of superposition of processes with different characteristic scales of operation (*Process 1* and *Process 2*) is illustrated using a hypothetical population dynamics of an insect species from the mountain birch ecosystem. The mean field of process 1 could represent a spatially homogeneous rate of immigration of the ("ballooning") autumnal moth *Epirrita autumnata* larvae during an early, warm summer season. These leaf-eating insect larvae can, under proper climatic conditions, displace themselves over quite long distances, simplified as a coarse-scaled immigration rate that is uniform over space. The rate can be expressed, for example, as the number of individuals per unit area per season. However, any process has a complementary "particle expression" in addition to a "field expression", in terms of statistical mechanics and particle kinetics. While rate of "raining" larvae represents the field (process) expression, spatial locations of individual larvae in the population of migrants represent the complementary "particle" (statistical pattern) view. This is illustrated by five *dots* randomly dispersed within the arena under study, representing a small and random subsample of female larvae. Each of the female larvae pupate in summer, and emerging adult females are not able to fly long distances. Thus, in comparison to the "mean field" ballooning dispersal process, the local movement process of adult females is very spatially restricted. Due to the restricted movements of females, dispersion of eggs from each female is also spatially restricted, defining a statistical pattern by the particle view that mirrors the locally fluctuating rates of process 2

21.2.3 Aspect 3: Beyond Superposition – Spatio-Temporal Effects from Non-Linear Responses

The presence of non-linear (i.e. non-proportional) functional responses combined with local neighborhood interactions between system components means that system simplification from coarse-graining of local details may mask important elements of the system's spatio-temporal processes. This means that one is unable to simulate this aspect of the system behavior realistically within the context of linear superposition.

For example, the probability that mountain birch trees at a given locality will be killed by insect attacks or removed by logging is a non-proportional function of the local forest's age or size class dominance: the probability of such a perturbation event is small except for older trees, where the probability increases non-proportionally with age. A local state variable – in this case the local abundance of birch trees – is not susceptible to a given perturbation unless another attribute of the local condition – age class in this case – has reached a given critical threshold (cf. Chaps. 9 and 12). Further, the susceptibility to "attack" also depends on conditions in the immediate neighborhood: a given old-growth stand may be considered more vulnerable to being logged, or attacked by insects, within a given increment in time if such a perturbation simultaneously appears in the neighborhood during this time increment. In statistical mechanical terms, this is often called "the domino effect", since the perturbation may spread in a cascading manner from "neighborhood to neighborhood" (see enclosed CD for Chap. 21, Fig. 21A).

In this case, a combination of local non-linear functional responses linked with domino effects may lead to complex spatio-temporal system behaviors that cannot be fully understood by studying local conditions alone. Both finer-scaled (i.e. subpatch) and coarser-scaled (i.e. the neighborhood at various scales) conditions must be taken into consideration, and the interactions are not manageable by classical modeling approaches. Another word for this phenomenon is scaling complexity, which cannot be modeled as easily as dynamics that can be compartmentalized in accordance with the superposition principle (Fig. 21.3).

Under scaling complexity conditions non-linear interactions can easily produce complex, multi-scaled "shifting mosaic"-like patterns of spatially extended perturbations spanning a large range of scales. Local interactions may under a broad range of conditions, where non-proportional (i.e. non-linear) responses are involved at fine scales, create complex patterns even at much larger scales than the typical scale where the pattern-generating process actually takes place.

This kind of multi-scaled, intrinsically generated pattern represents what is called emergent properties: complex patterns that neither are explicitly defined by specific local interactions nor can be understood as superpositions of coarse-scaled forcing functions. The patterns appear as "by-products" of local, fine-scaled interactions, e.g. in mountain birch forests. The system behavior can in this case only be properly revealed by applying model simulations.

As the HIBECO model simulations show (see below and Chap. 22), the intrinsic mechanisms related to scaling and aggregation provide important challenges for management in its own right. An alternative approach to modeling this ecosystem would have been to "cut some corners" and use one or another traditional model framework that behaves in a way that is more easily manageable, both numerically and analytically within mainstream mathematics and statistics.

We believe, however, that it is more fruitful for the sake of future contributions to practical guidelines for management of northern birch forest ecosystems to consider practical expansions of the traditional landscape ecological model framework based on theories that are able to handle complex interactions explicitly. This development will go far beyond the HIBECO project in both extent and time, and is an interdisciplinary task involving a large and quickly growing community of engaged scientists.

21.3 The HIBECO Model

A main goal of the HIBECO project has been to explore and analyze the primary human-related factors driving the mountain birch ecosystem functioning on a local and regional scale. In this way, the project contributes to the development of guidelines for political organizations with direct or indirect influence on sustainable human exploitation of resources in this ecosystem. The ecosystem components that are covered by the project span aspects as diverse as birch growth and distribution under various climatic regimes in space and time (Chaps. 1–5), bud dynamics, genetic adaptations of local birch populations (Chaps. 6 and 7), trampling and other effects by humans and animals (Chaps. 14 and 15), and herbivory influences from insects (Chaps. 9 and 12) and ungulates, mainly sheep in Iceland, Greenland and Scotland (Chap. 10), and also reindeer in northern Fennoscandia (Chaps. 11 and 19). Direct human exploitation of birch trees in forestry, for firewood, and for various cultural uses has been described and analyzed (see Chaps. 16, 18, 23–25). As illustrated below, these elements involve modeling challenges connected to complicatedness as well as complexity.

Computer modeling of various disturbance and management regimes at the landscape scale has gained momentum over the last decade (Boyce and Haney 1997; Waring and Running 1998; Mladenoff and Baker 1999). In the HIBECO project, computer simulations can function as an instrument linking various aspects of the HIBECO project closer together. HIBECO is an interdisciplinary project, and proper modeling requires explicit qualitative and quantitative descriptions of essential variables and parameters and their dynamic interactions. For example, model scenarios may be used to explore complex ecological interactions in space and time at various mountain birch landscape scales. Further, model results may contribute to basic scientific insight that could not be achieved by combining fieldwork, experiments and "educated guesses" alone (Gautestad and Wielgolaski 2001). Modeling work may also have practical value for management and politics related to sustainable use of birch forest resources and maintenance of the northern birch forest ecosystem (see Chap. 22).

The model includes spatially explicit algorithms for handling single- and multi-scaled processes related to management regimes involving tree harvesting, grazing effects from sheep and reindeer, climate change effects and perturbations from occasional outbreaks of leaf-eating insects. The model has been developed in the framework of Microsoft VB 6.0 programming language.

This model, referred to as "The HIBECO Model", is a dynamic, spatially explicit model with grid cell dynamics and neighborhood interactions that may cover a range of spatial scales. The focus for the current version is on the main interactions related to anthropogenic influences and herbivory, integrated as various "perturbation regimes" superimposed on birch forest growth dynamics with basic birch demography.

Further, the model is used to explore these direct or indirect human vs. birch ecosystem interactions under a gradually changing climate regime: scenarios under a realistic set of temperature changes over a period of, for example, 50–100 years or more can be produced for model landscapes with various topography and regional moisture conditions (continental vs. oceanic climate).

21.3.1 The Model Arena

The model dynamics is programmed to be distributed over a virtual landscape that is split into a grid of 128 × 128 grid cells, or "pixels". The default cell size is defined as 100 × 100 m^2 (1 ha), meaning that the 16,384 cells cover an area of 12.8 × 12.8 km^2. At each time increment of 1 year, the local variables and conditions (including any change in forcing functions) are updated in parallel in all cells in accordance with the execution of the "rules" that govern the internal forest growth and interference dynamics in each cell.

The intracell mountain birch demography has two alternative modes of expression in the simulations: one simplified mode where cells with forest cover are described with one variable, the average birch tree size class for the given cell, and one mode where intracell birch tree demography is modeled explicitly with age class variables (see enclosed CD for Chap. 21, Fig. 21B, for details).

Only mountain birch is explicitly included in the forest cover, since this species, according to the definition in the HIBECO project, dominates the current tree layer in many parts of its distributional range, at least at the pixel scale of 1 ha and larger. Another important reason is that birch can be expected to dominate as a pioneer tree species as the tree line shifts during improved climatic conditions.

21.3.2 Implementation of Landscape Heterogeneity

Initial abiotic and biotic conditions for mountain birch forest growth and survival can be set to be homogeneously or heterogeneously distributed within the model arena. Homogeneous conditions mean that all cells in the arena have the same a priori abiotic starting conditions for the local mountain birch trees, so that birch forest growth and survival are statistically similar among the cells. Under homogeneous landscape conditions, the birch forest covers the entire model arena. This simplified "landscape" is ideal for studying shifting forest mosaics from a phenomenological perspective. However, in many simulation studies with relevance for birch forest management in actual regions, attributes from real, heterogeneous landscapes are implemented, not only at the scale range from 1-ha cells to the entire arena size, but also to some extent at the intracell level (see enclosed CD for Chap. 21, Fig. 21B).

In a heterogeneous landscape, the local variables and parameters that contribute to the actual expression of the rules will vary across the landscape and generate a pattern of forest growth and survival in accordance with these

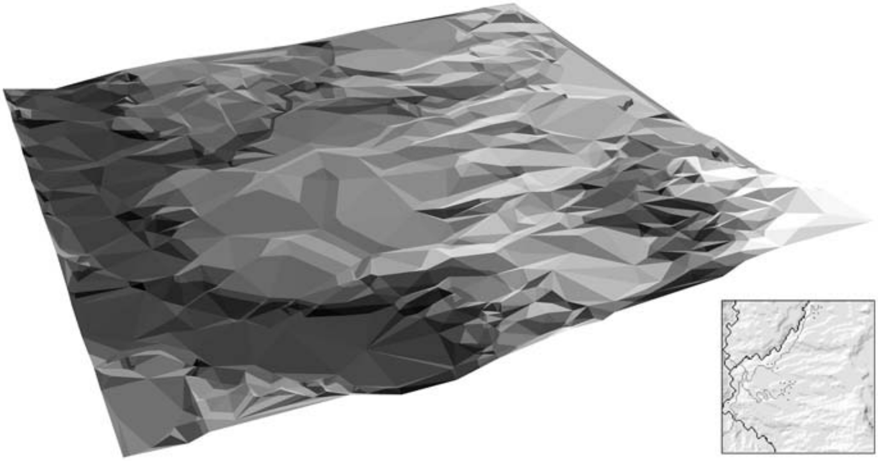


Fig. 21.4. A three-dimensional representation of a model arena of 12.8?12.8 km^2. The *smaller image* shows a two-dimensional version, where layers (GIS themes) for local roads, rivers and cabins are superimposed

locally varying conditions. In this case, the model landscape structure is built on superimposed GIS layers (themes) for topography, rivers, roads, cabins and other landscape attributes. For example, a virtual arena with valleys and mountains typical of an oceanic, montaneous climate regime in northern Norway (e.g. in Troms county) has been used extensively in the HIBECO model simulations (Fig. 21.4). The altitudinal range in the figure is 1000 m from the bottom of the valley to the highest mountain peak. In this region mountain birch is the dominant species in the subalpine zone, and it is the dominant tree species close to the upper-altitude forest border. The forest line definition is described in the enclosed CD for Chapter 21 (Fig. 21B).

21.3.3 Management Regimes and Perturbations

Local conditions can be set to vary over time and space, defined as various types of "perturbation events" (time-specific) and "chronic influences" (repeating itself continuously over time), during a given simulation sequence. For example, a management regime based on a specific set of logging practices, "rules", may be implemented for the simulations. In this case, the local trees in a given cell area or a local group of cells may be logged according to the specified rule. The rule defines the spatial distribution of which cells will actually be subject to logging during any given time interval (see Chap. 22).

In addition to the simulation of logging practices for spatial scales of 1 ha and larger, which regards primarily future potential management practices, the HIBECO model also implements finer-scaled tree-cutting practices. Birch trees are traditionally mainly harvested for firewood and wood material for art and handicrafts (see Chaps. 18 and 24). Local culture in the northern parts of Scandinavia involves old traditions of active thinning of birch stands and selection of specific stems based on specific rules and experiences (Aikio and Müller-Wille 2002). Within the HIBECO model, this kind of harvesting at the scale of single trees or smaller groups of adjacent trees is implemented as one of the components of the age-specific mortality rates for birch stems at the scale of 1-ha cells.

In addition to various forms of forest harvesting, natural mountain birch forest dynamics in northern Scandinavia is also subject to perturbations from major outbreaks of leaf-eating insects, in particular the autumnal moth *Epirrita autumnata* and winter moth *Operophtera brumata* (Tenow 1972; Haukioja et al. 1988; Bylund 1995). Sometimes these outbreaks may cause severe damage to the forest due to defoliation. A complex mosaic of local birch stands with dead and less affected trees is the result of combinations of stand history and age, moth egg survival during the last winter, moth larvae dispersal and other factors (see Chaps. 9 and 12). This important mountain birch forest-influencing process is included in the model. Winter temperature inversion events may be a frequent reason for local extinctions of total populations of moth eggs along the lower elevation parts of valleys in northern Scandinavia (Chaps. 9 and 12). In the HIBECO model, severe damage to birch forest stands by moth larvae is simulated as an occasional year-specific perturbation event: A severe outbreak is invoked over the model landscape, where a randomly chosen percentage of local cell areas that are classified as old-growth stands are subject to increased death of old-aged stems, given that last winter's minimum temperature was above the critical level for moth egg survival, and location is in or below the zone for maximum summer temperature along an altitudinal gradient. We have not included any kind of long-term periodicity in these insect perturbations, since historical data from various locations and regions show an inconsistent statistical pattern in this respect (Chap. 9). Only rarely does an outbreak have a substantial effect on birch stem death rate, and thus on the forest mosaic, at spatial scales of 1 ha and larger. The latter implies that a forest may be attacked and severely defoliated more or less periodically, but still not killing forest stands other than during more infrequent events when the stands are attacked several years in succession.

Grazing pressure from ungulates, free-ranging sheep and reindeer is an important factor in mountain birch regeneration dynamics (see Chaps. 4, 10, 11, 17). While logging and forest stand killing from insect outbreaks are modeled as episodic perturbation events, grazing from ungulates is primarily incorporated in the form of age class-specific increased mortality rate on young age classes of birch. An extra strong grazing pressure – an intense grazing event rather than a chronic grazing pressure – can also be defined for the actual logging year for logged cells. This makes it possible to study a holistic management model where logging in combination with the added effect from grazing animals may contribute to keeping some parts of the landscape deforested or more fragmented, as a potential management strategy in case of strong birch forest expansion during improved climatic conditions (see Chap. 22).

21.3.4 Climate Change Scenarios

Local mountain birch growth can also be said to vary due to a changing climate. Figure 21.5 illustrates this in the form of a gradually shifting forest line, where an episodic perturbation from a severe moth outbreak is also shown. In a recent report on regional climate change scenarios from modeling, it was concluded that the most probable annual increase in temperature in Finnmarksvidda could be more than 0.4 °C per decade (see Chap. 1). Because of an expected increase also in winter precipitation, mainly as snow in more elevated and continental areas, these two factors may to some extent cancel each other out in inner, northern Fennoscandian regions and at high elevations when it comes to net influence of climate change on onset of spring and

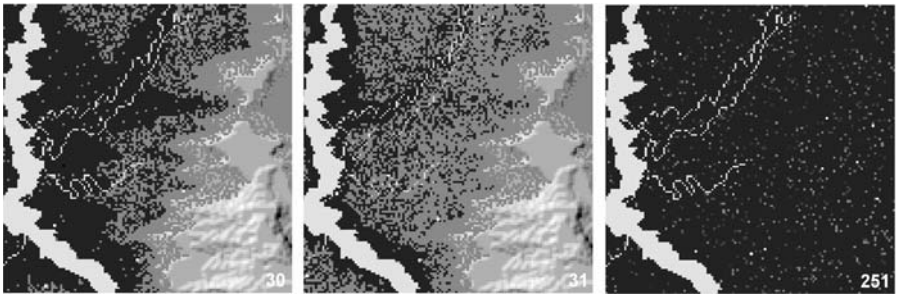


Fig. 21.5. The model arena from Fig. 21.4 is here superimposed with a layer describing birch forest cover and its dominating stand age at a pixel scale of 1 ha at three temporal snapshots, simulation steps t=30, t=31 and t=251. A gradient from *light* to *dark shades of gray* describes grid cells that are dominated by young- and old-growth mountain birch forest stands, respectively. At an improved climate for tree growth during this period, the successive annual steps t=30 and t=31 are chosen to show the effect from a major (i.e. forest stand killing) moth outbreak at t=30 the following year, and t=251 illustrates the birch forest after it has regained its overall long-term equilibrium of homogeneous old-growth stands at coarse scales, with some scattered and recent clear-cuttings from logging that are visible at fine scales. These loggings are seen as a random scatter of local small-scale (1-ha) *grayish dots*. *White dots* show cells that were logged at the actual time step. At t=30 a young forest zone appears at intermediate elevation, due to an expanding tree line from a gradually warmer summer climate during the period t=1 to t=30. At t=30 a severe moth outbreak kills a large part of the old-growth forest, which consequently is reset to young mountain birch forest stands at t=31. Critical winter temperature levels have killed overwintering moth eggs below the inversion zone along the bottom of the valley between t=29 and t=30, leaving old-growth stands undisturbed at t=31 in this zone

length of growing season (Høgda et al. 2001). In more oceanic areas of northern Norway, the climate change is expected to have a real and positive influence on the onset of spring and thus on the length of the growing season. In the HIBECO model, climate change is implemented as a 10-year incremental increase of 0.4 °C magnitude in the 3-month maximum temperature index. This in turn initiates a spatial shift in the isotherm that defines the forest line (see enclosed CD for Chap. 21, Fig. 21B).

In the model's climate change scenario for the Norwegian oceanic Troms region, it is assumed that the shift in the forest line is immediate, i.e. birch seedlings are sprouting (even if seedlings may not appear above the surrounding vegetation for several years) without time delay over the new altitudinal zone that is made available by improved climatic conditions. Seed dispersal distances in birch (Aradottir and Arnalds 2001) can be considered large enough to make this "immediate climatic response" a feasible assumption for the current model landscapes. However, due to a possibly unchanged or even delayed spring in continental regions, the yearly biomass production may be influenced in more subtle and complex ways (see Chap. 4).

21.4 Simulation Examples

The simulation results in Fig. 21.6 illustrate the system "mechanics" from the basic elements in the model, with emphasis on climate change and (over)grazing effects on long-term forest development. The time series show that a gradually increased growth season due to improved summer temperature (see above) leads to an expanding front of young birch forest drifting towards higher elevations in the landscape, in synchrony with the gradually changing thermocline. The effect from grazing is in this example clearly visi-

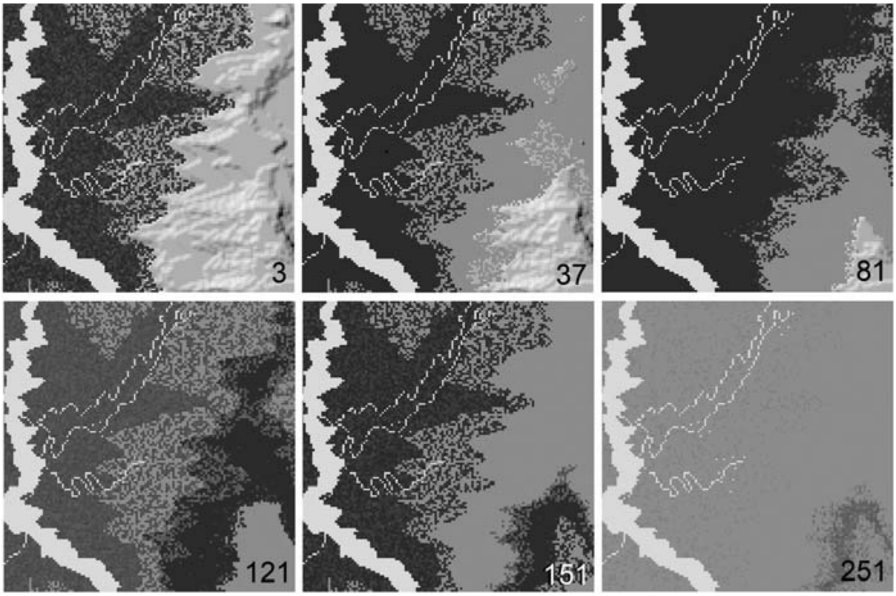


Fig. 21.6. In an independent simulation series compared to the one shown in Fig. 21.5, the influence of climate change conditions, forest harvesting policies and ungulate grazing pressure effects in the absence of major moth outbreaks is illustrated (see further explanation in text). The snapshots *t*=3 and *t*=37 show how climate change at the given rate expands the young-growth forest first (for obvious reasons), while older growth areas increase later due to aging of the new forests, as shown at *t*=81. Due to the dynamic feedback between birch growth and forest disturbance rate at old growth patches (logging) and young growth patches including understorey of older forest (grazing), some kind of dampened oscillation of old growth stand cover can be seen when comparing snapshots from *t*=81, *t*=121 and *t*=151. Breakdown of the forest cover is not obvious before the last snapshot, *t*=251 (it differs from the picture at *t*=251 in Fig. 21.5 due to different disturbance simulations), which shows that no further increase in old growth takes place (in contrast to the lower elevation parts in *t*=121 vs. *t*=151). The forest has relatively suddenly turned into open grazing fields with scattered birch patches of mainly young birches due to 200 years or so with unsustainable utilization intensity of the birch forest

ble after ca. 80–100 years, since chronic grazing pressure has removed a too large part of the regeneration during this time span, and open and young-stand areas begin to dominate when the old birch generation gradually disappears due to old age. The grazing pressure has in this particular scenario been too intense to allow for a minimum yearly survival rate of the younger age classes to replace dying old trees during this period (logging is also present in this scenario, but constrained to finer spatial scales than the grid cell size, making the small, scattered clear-cuttings invisible at this resolution). After ca. 200–250 years, the overgrazing manifests itself as open fields with only scattered patches of birch forest and trees. Some element of dampened oscillations that can be seen in the series up to this point is due to the long-term intrinsic feedback mechanism between forest growth and grazing.

Even if series of this length are of little value as actual predictors of a given real landscape several hundred years in the future, these kinds of long-term scenarios are still important to illustrate long-term consequences of current management choices, i.e. they are of value as material for deciding on sustainable management policies today. For example, maintaining a high grazing pressure in combination with forest logging of given magnitude is shown here to be non-sustainable under the given conditions, but this is not obvious until the system has progressed for a period of 150–250 years in this series.

By running simulations like these, one can offer northern mountain birch forest management a range of scenarios, and these scenarios will hopefully initiate a discussion about model parameters, functional relationships and other aspects that will bring forward even better and more detailed simulations in turn (cf. Chap. 22).

With no forest perturbations (at grid cell scale or larger) or local variations in growth conditions, simulations from "stochastic growth" conditions (explained in the enclosed CD for Chap. 21, Fig. 21B) eventually lead to a homogeneously distributed old-growth mountain birch forest covering the entire arena that is defined to be accessible for birch growth. A similar result will emerge from deterministic growth mode simulations (see definition in the enclosed CD for Chap. 21, Fig. 21B), but here the equilibrium conditions are more "fluid" due to the constant flux of trees growing out of one age class and into another: for every time step, birch stems of all age classes are subject to age-specific growth rates, death rates and regrowth rates in accordance with the current parameter space. The influence of, for example, logging on this natural birch tree population dynamics will create feedback effects, maintaining more or less complex time series fluctuations in age-class densities even when averaged spatially over the scale of the entire arena (Fig. 21.7). Over time, though, a balance is reached where the density undulations in time and space follow a never-ending statistical pattern, ranging from practically stable densities (simple balance), as illustrated in Fig. 21.7a, to stronger and more complex fluctuations (i.e. balance in a statistical sense, like stabilization of long-term fluctuation mean, variance and higher

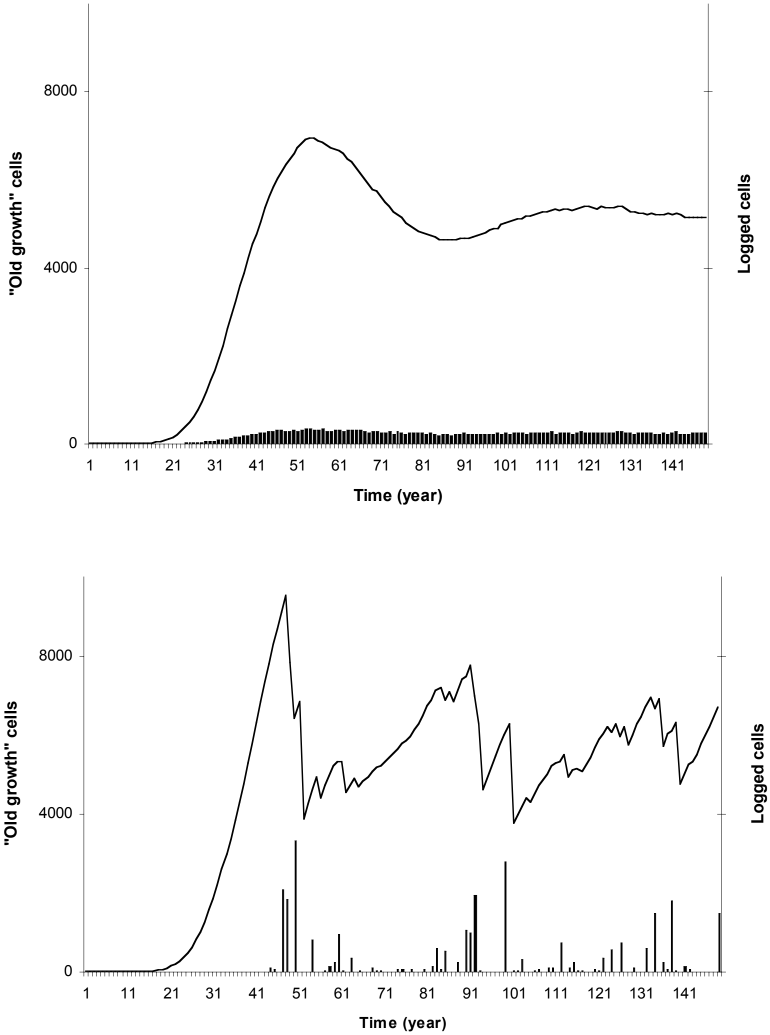


Fig. 21.7. a Time series showing old-growth cover (*line*), expressed as number of cells in the model arena with mountain birch forest cover dominated by size class 10 on a scale from 1–10. The forest is logged in accordance with a practice that limits size of individual clear-cuttings to small spatial scales. Number of logged cells is shown as *bars*. Starting from young and medium-aged forest stands, the arena shows an increased abundance of old forest as time goes by. However, some undulations can be seen before an equilibrium state is reached both in cover and yearly logging quantity after ca 150 years. **b** When logging practice is replaced with an alternative logging rule leading to a more heterogeneous and multi-scaled shifting mosaic of forest of various age classes (see Chap. 22 for details), year-to-year fluctuations in old-growth forests (*line*) are often strong, reflecting a large variation in yearly logging intensity (*bars*) due to the modified rule. No long-term equilibrium in cover or logging rate is observed. Still, the long-term average cover of old-growth stands, ca 5000 cells in this example, is similar to **a** after the initial transient period of forest establishment

moments, or series length-dependent rates of change of these moments), as shown in Fig. 21.7b.

Under some conditions, complex feedback mechanisms between intrinsic forest growth and survival rates and extrinsic influences from, for example, tree harvesting by logging and ungulate grazing may induce complex fluctuations for the model arena's birch forest state variables. In a time series, this may appear as periodic or more complex – even fractal ("scale-free") – fluctuations in the time series for regional (arena-scale) tree densities of given age classes (cf. Chap. 22).

This is a good example of an emergent system property (as defined for level three complexity above). Intracell fluctuations in, for example, old-growth tree abundance follow a succession-like pattern with pseudo-periodic logging intervals, while an old growth state variable for the entire model landscape shows very complex fluctuations in space and time that may be scale-free over several orders of magnitude (a temporal aspect of these spatio-temporal fluctuations can be particularly imagined from Fig. 21.7b). This range in scale-free fluctuations will increase with increasing arena size for the simulations (see Chap. 22).

21.5 Discussion and Conclusions

The main focus of the HIBECO model has been to prepare a virtual arena where general growth and dispersion patterns for subalpine, subarctic mountain birch forests can be simulated in a fairly realistic manner for the purpose of studying the consequences of various management and perturbation regimes. Under model conditions of stable and changing climate conditions, scenarios related to various anthropogenic influences and herbivory influences from ungulates and leaf-consuming insects with periodic outbreaks have been studied at a preliminary level of detail. Our current implementation of moth outbreaks is a strong simplification of the intrinsic and extrinsic forces that influence the complex spatio-temporal fluctuations in severe defoliation events. However, the HIBECO model may be expanded at a later stage with a more explicitly defined population dynamic submodel for the actual moth species and their main predators and parasitoids (see Chaps. 9 and 12 and Fig. 21.3, where conceptual models for some of the elements in this kind of submodel are described).

In the current scenario example, grazing effect from ungulates is modeled to be stronger in cells dominated by young stands, such as recently logged areas and pioneer forest growth in the expanding front under improved climatic conditions, than in medium- and old-aged stands. In general terms, we have assumed in the model that medium and old-growth sites are generally less penetrable and have less grazing resources (due to less light penetration to the forest floor) than sites dominated by young stands (cf. Chap. 22). However, a more complex pattern may emerge if the grazing is strong and long-lasting (many years). In this case, the understorey may be opened up due to local habitat facilitation. At this stage we have not implemented this complex effect in the model.

The current version of the HIBECO model is still in an early developmental phase with respect to the level of detail that is necessary before it can be distributed as a tool for applied science to produce scenarios and analyses connected to particular areas and specific management contexts. At this stage, efforts are concentrated on aspects related to general management principles, and simplified, virtual landscapes are used for this purpose. The advantage of a virtual landscape is that it allows for a structure that is optimized for exploration of the basic mountain birch ecosystem processes in the context of various management and climate scenarios. The focus is then more stringently aimed at capturing the main system processes typical or representative of a broad region rather than a specific, local area with all its particular and explicit landscape details. When the model behavior is sufficiently understood at the current generic level, one can bring in more details to the simulations in the next turn.

Acknowledgements. Special thanks are extended to O. Tenow, H. Bylund and S. Karlsson for providing unpublished data on age-specific birch stem growth rates. We also thank other HIBECO project colleagues for their contributions and professional opinions on many aspects of the various elements that were implemented in the model.

References

Aikio MS, Müller-Wille L (2002) Living at the timberline – the Sámi and the mountain birch forests in northernmost Europe. Finn For Res Inst Res Pap 862:40–56

Aradottir AL, Arnalds O (2001) Ecosystem degradation and restoration of birch woodlands in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris, and Parthenon, New York, pp 293–306

Boyce MS, Haney A (eds) (1997) Ecosystem management: applications for sustainable forest and wildlife resources. Yale University Press, New Haven

Bylund H (1995) Long term interactions between the autumnal moth and mountain birch: the roles of resources, competitors, natural enemies and weather. Swedish University of Agricultural Sciences, Uppsala

Cappuccino N, Price PW (eds) (1995) Population dynamics: new approaches and synthesis. Academic Press, San Diego

Gautestad AO, Wielgolaski FE (2001) Dynamic modeling of the mountain birch forest ecosystem: challenges related to space, time and scale. Skógræktarritid 1:145–150

Haukijoja E, Neuvonen S, Hanhimäki S, Niemelä P (1988) The autumnal moth in Scandinavia. In: Berryman AA (ed) Dynamics of forest insect populations. Patterns, causes, and implications. Plenum Press, New York, pp 163–178

Høgda KA, Karlsen SR, Solheim I (2001) Climatic change impact on growing season in Fennoscandia studied by a time series of NOAA AVHRR NDVI data. In: Proc International Geoscience and Remote Sensing Symp , 9–13 July, Sydney, Australia. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey, pp 1–3

Kaneko K (ed) (1993) Theory and applications of coupled map lattices. Nonlinear science: theory and applications. Wiley, Chichester

King A (1991) Translating models across scales in the landscape. In: Turner MG, Gardner RH (eds) Quantitative methods in landscape ecology. Springer, Berlin Heidelberg New York, pp 479–517

Mladenoff DJ, Baker WL (eds) (1999) Spatial modeling of forest landscape change: approaches and applications. Cambridge University Press, Cambridge

O'Neill RV, King AW (1998) Homage to St Michael; or, why are there so many books on scale? In: Peterson DL, Parker VT (eds) Ecological scale: theory and applications. Columbia University Press, New York, pp 3–15

O'Neill RV, DeAngelis DL, Wade JB, Allen TFH (eds) (1986) A hierarchical concept of ecosystems. Monographs in population biology 23. Princeton University Press, Princeton

Shugart HH, Urban DL (1988) Scale, synthesis, and ecosystem dynamics. In: Pomeroy LR, Alberts JJ (eds) Concepts of ecosystem ecology. Springer, Berlin Heidelberg New York, pp 279–289

Tenow O (1972) The outbreaks of *Oporinia autumnata* Bkh. and *Operophtera* spp. (Lep., Geometridae) in the Scandinavian mountain chain and northern Finland 1862–1968. Zool Bidr Uppsala Suppl 2:1–107

Waring RH, Running SW (1998) Forest ecosystems: analysis at multiple scales. Academic Press, San Diego

22 Scenarios for Future Development of the Mountain Birch Ecosystem

A.O. GAUTESTAD, F.E. WIELGOLASKI, B. SOLBERG and I. MYSTERUD

22.1 Introduction

The HIBECO model (Chap. 21) is an integrative model aiming at capturing some of the important northern mountain birch forest ecosystem processes with respect to management and sustainable use of this system under the influence of climate change. Relatively flat regions close to the current tree line, like Finnmarksvidda in northern Norway, are particularly susceptible to climate change (see Chap. 1) affecting birch forest cover, since the tree line may move over large regions relatively quickly. If this scenario holds true, it may have profound effects on the sustainability of traditional uses of large alpine areas which in lesser or greater part can be expected to be engulfed by a relatively rapid progressing front of subalpine forest. For example, the regional cultures of reindeer herding may experience increased challenges from forest expansion (see Chaps. 4, 17, 19) unless continued access to specific summer and winter grazing areas is maintained, as well as uninterrupted migration routes between these areas. The potentially denser and more extensive cover of mountain birch forest in the future, in parallel with contracting alpine areas due to the shifting tree line, represents a scientifically supported prediction that needs to be taken into consideration when it comes to strategic management policies for these regions.

A broader future dominance of medium- and old-aged birch forest means lesser productivity of – and lesser dominance of – the ungulates' main food resources due to shading effects (cf. Chap. 19), combined with interspecific competition for critical mineral resources between trees and plants in the understorey. A denser forest also leads to increased movement constraints because of, e.g., fallen, dead stems and denser understorey creating obstacles for free-ranging grazing animals commuting between preferred feeding patches (cf. Chap. 17). Even if natural constraints on birch growth will still exist at local scales behind the new moving tree line, such as uninhabitable patches for birch trees and interspecific competition with existing plant com-

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

munities, one can still expect large areas in and beyond the current subalpine–subarctic ecotone to be dominated by new and dense mountain birch forest in the future if this development is left alone without active forest management in critical sites and regions.

With relevance to this challenge we will show how simulation results from various forest management policies may not only reveal intuitive results but also produce quite counter-intuitive results related to the shifting mosaic of forest stands in space and time due to specific logging practices, or rules. Lessons from model scenarios like these will be important for current and future management of the birch forest ecosystem in these areas, due to the importance of maintaining an optimal level of multi-use landscape heterogeneity and interpatch connectivity, and thus possibly also biodiversity in a more broadened ecological context.

22.2 Logging Practices and the Shifting Forest Mosaic

The "shifting mosaic" term has a long history in theoretical and practical forest ecology (Pickett and White 1985). More and more focus has been put on understanding spatial and spatio-temporal aspects of the succession dynamics (Reice 1994; Hay et al. 2001), rather than considering a specific fixed forest patch as it evolves in time in isolation from the surrounding landscape. Self-managed forests have their own complex spatio-temporal and intrinsically driven structure (Franklin and Woodcock 1997). Feedback mechanisms, involving factors like forest fire dynamics, insect outbreaks, grazing by animals and inter- and intraspecific competition, contribute to a self-maintained and complex process that forms the heterogeneous landscape of young stand patches, old-growth stands, and everything in between. The spatial pattern of forest patches of various age classes one particular year will be different from the spatial pattern one or more tree generations later. In other words, a naturally maintained forest structure can be described as a spatio-temporal shifting mosaic with a self-maintained degree of intrinsic, complex heterogeneity that typically is spread over many spatial scales. In addition to this menagerie of natural pattern-generating factors, human presence has also put its own distinctive mark on the forest dynamics and mosaic structure (cf. Chaps. 16, 23–25).

The spatial regrowth pattern of various forest types strongly depends on the long-term logging practices that have been performed during the year-to-year harvesting. These logging rules traditionally vary from place to place, and are strongly influenced by local conditions like topography, distance from roads, forest productivity, and so on. However, more than anything else, the modern clear-cutting method that has dominated over the last 50 years or so in productive coniferous forests at lower elevations has gradually reformed the predominant intraforest mosaic in Fennoscandia, as in many other regions around the world.

The northern mountain birch forests closer to the climatic forest border have so far generally not been utilized strongly by extensive, industrial-level harvesting. This is mainly due to the relatively low net productivity levels in these "fringe birch forests" close to the climatically determined tree line, but is also due to small and scattered communities in and close to these areas (see Chap. 16). Some parts of the birch biomass yield in the subalpine, subarctic zone have been traditionally harvested for the purpose of firewood, handicraft material and other uses through scattered tree cuttings and more extensive clear-cuttings (see Chaps. 18, 23, 24).

The gradual reforestation and forest densification processes, e.g. due to lower grazing pressure (see Chap. 17) and climate change, may contribute to significant movements of the forest border into current alpine and arctic areas (see Chaps. 4 and 21). The question is then whether current tree cutting and forest management levels and practices can cope with this challenge of broad-range forest expansion, or whether new management practices are needed to maintain current levels of open areas in at least some local areas where this is most crucial for traditional uses of the subalpine and alpine ecosystems for, e.g., grazing field mosaics for reindeer and free-ranging sheep. It may be shown that the choice of logging practices involves more than choosing an optimal level of logging intensity. It is illustrated below how a gradual shift from a traditional, so-called scale-specific logging rule to a multi-scaled ("scale-free") rule that spans an increasing range of spatio-temporal scales will have a profound effect on the forest's shifting mosaic in the long term.

The traditional logging rules are typically scale-specific in a spatial context. For example, the tradition of cutting trees in a scattered manner throughout the forest is limited to a spatial scale of, say, a few square meters for the individual logging events. This means that in order to see the pattern that emerges from this practice in a spatial model, we need a resolution of this "grain" size or smaller.

Even the more industrial clear-cutting policies are scale-specific. However, here the characteristic scale for the mosaic-enhancing process from logging is shifted upwards in spatial scale to a few hectares, i.e. the typical upper limit of clear-cuttings. At coarser spatial scales, even industrial clear-cuttings will be "averaged out" from the remaining forest mosaic at these coarser scales.

The reason why these traditional logging rules are scale-specific is based on the fact that each rule imposes a constraint on how large – in spatial terms – a specific logging event should be. Logging of individual trees or small groups of trees rarely influences the probability of similar logging of trees nearby. Thus, scattered logging of individual trees and small groups does not contribute to forest age class pattern (shifting mosaic) at scales much above this fine-grained spatial scale.

Similarly, a specific clear-cutting does not increase the probability that the surrounding forest will be logged sooner than similar forest stands farther away. In geostatistical terms, this can be expressed as relatively short spatial autocorrelation lengths relative to the landscape scales.

On the other hand, we could consider a more "scale-free" logging policy. This means that we do not impose spatial constraints on the extent of a particular logging event; we simply log the entire chosen stand of old growth, whether this means a clear-cutting of 1, 20 or even 1000 ha. In model terms, we chose a random old-growth patch, and then expand the clear-cutting in all directions until a borderline with non-old forest is reached. In other words, the complete old-growth stand is logged, not just a given portion of it, defined by a rule for maximum clear-cutting size. This "idealistic" scale-free rule should of course be modified to something that can be implemented in practical terms, for example by defining an upper maximum clear-cutting size. The logging rule will then be "scale-free" only up to this spatial scale. Other modifications are also possible.

The upper limit of individual clear-cuttings is a controversial theme from a forest conservation point of view. However, a strong constraint on clear-cutting size (as with the current logging policy) will fragment the forest in the long run, and consequently also limit the presence of continuous and large old-growth forest sites. A more "free" distribution of clear-cutting sizes (i.e. a mixture of large and small clear-cuttings) will also increase the long-term presence of larger fragments of old-growth forest. These aspects are clearly illustrated in the simulation results below.

In order to simplify the current simulations, we used a homogeneous arena, constant climate conditions and ran one logging rule at a time. In this way, any spatio-temporal pattern that emerged would be the result of intrinsic forest dynamics with the actual logging rule as the driving force, rather than a mixture of intrinsic and extrinsic pattern-generating processes. By focusing on a relatively narrow level of forest harvesting intensity, we could thus focus explicitly on qualitative differences among various rules when it comes to mosaic patterns in statistical terms. For example, by defining a long-term logging output goal for the defined model arena (i.e. X m^3 of old-growth birch wood per year on average, where X is a realistic harvesting rate), we can study qualitatively effects from various logging rules more directly than if we vary the rules as well as the intensity of harvesting. On the other hand, we can show that variations in overall harvesting rate will also influence the forest mosaic pattern, and the sensitivity in this respect will depend on the rule for the given scenario.

We can consider the "grain size" ("pixel size") of the model arena to be ca. 10 m^2 if we think of the pattern as scattered cuttings of individual trees or a small group of trees (say, one or more stems from a polycormic tree). For industrial clear-cuttings, we can consider the pixel size to represent, for example, 1, 2, 5 or 10 ha, depending on the characteristic upper clear-cutting size that is determined for a specific region. The major point in this respect is the spatial constraint that is implicit in the logging rule, not the actual size of this spatial scale as such, since we focus on the effects at coarser scales in relative terms. For the current model simulations, the landscape (arena size) is defined as 128 × 128=16,384 pixels (cf. Chap. 21).

One could argue that time series beyond 50-100 years or so will have little relevance for practical forestry and ecosystem management of today due to uncertainties related to, e.g., ecology, economy and climate throughout the period. However, longer time series are crucial from two independent perspectives. First, any management practice should have a perspective of at least a few birch tree rotation periods in order to evaluate its sustainability values, since the forest mosaic pattern that emerges from a given shift in practice starting today may need that long time to stabilize itself in the practice-dependent pattern in qualitative terms (for example, see Figs. 21.6 and 21.7 in Chap. 21). Model scenarios involving short time series such as 50–100 years will not reveal the "drift" towards the new long-term pattern. Second, long time series are needed for proper material for statistical analysis when comparing various practices. The initial "drifting" period for a new logging policy to be fully reflected in the spatio-temporal forest mosaic is removed from the analysis in the following text.

22.3 Scenarios for Various Long-Term Management Practices

Figure 22.1 summarizes the typical forest mosaic that emerges from consistent and long-term implementation of scale-specific (upper row) and scale-free (lower row) logging practices, in the form of typical snapshots of the HIBECO model arena (see Chap. 21). In the upper row, we can easily see the long-term effect from a random scatter of yearly independent logging events, where each clear-cutting is constrained to a small spatial extent at the scale of the spatial resolution of the model arena. The overall impression is a homogeneous, fine-grained forest mosaic, where the pattern is constrained to relatively fine spatial scales. In a real, heterogeneous landscape with varying local conditions for forest establishment and growth, it is easy to imagine that the forest pattern at coarser scales than the pixel (grid cell) size in this case would first and foremost be the result of environmental factors, not of intrinsic dynamics due to the logging policy as such.

In contrast, the lower row shows a typical pattern resulting from a scale-free logging rule. High-intensity logging as shown in Fig. 22.1 (left-hand picture in the lower row) brings average long-term cover of old-growth stands down to 15 %, similar to the overall cover in the left-hand picture in the upper row. This policy produces a more "fine-scaled" mosaic than the less intense

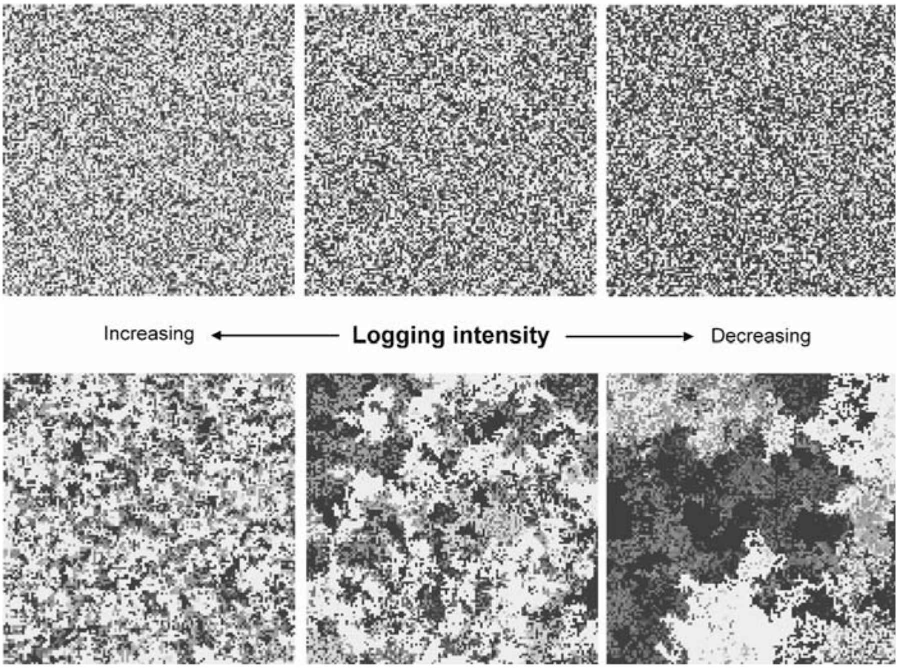


Fig. 22.1. Snapshots from a spatial model arena under scale-specific (*upper row*) and scale-free (*lower row*) logging rules. See main text for details. *Light shading* indicates young and recently logged stands, *dark shading* old-growth stands at the chosen points in time. The *right-hand pictures* in each row show the forest mosaic where long-term logging intensity has been more moderate than in the snapshots to the left. Thus, old-growth forest is more dominant in the right-hand snapshots, covering ca. 30 % of the area in both rows, while old growth covers ca. 15 % of the area to the left in both rows

logging scenario to the right with 30 % old-growth cover on average, but still a much more heterogeneous pattern than the scale-specific results for similar old-growth cover to the right in the upper row. A scale-free kind of logging thus produces forest stands where any given age class shows a more clumped dispersion, in particular when logging intensity is relaxed. This contagiousness is distributed over a large range of spatial scales: a small number of large stands of a given age class are mixed in with a larger number of smaller stands and an even larger number of even smaller stands. Statistical analysis (not shown here) reveals a so-called fractal, or scale-free, pattern.

We underscore that this pattern is a result of intrinsic dynamics, taking place in a model environment that is as homogeneous as in the upper row. Thus, in a real, heterogeneous landscape with varying local conditions for forest establishment and growth, it is (in contrast to the scale-specific results) clear that the forest pattern at coarser scales than the pixel size in this case will be a non-trivial, complex mixture of influences from environmental factors and intrinsic dynamics, where the latter is independent of the environment as such.

Our simulation experiments showed that for the scale-specific rule it was, as one might have expected, necessary to double the frequency of logging events to reduce the overall, long-term cover of old-growth stands to half, i.e. from 30 % cover to 15 % cover on average. With the scale-free rule, however, it was necessary to increase the frequency of logging events dramatically, from one logging event per 2.5 years on average to 100 events per year on average in order to obtain the same long-term reduction in old-growth cover. Further, with the scale-specific rule, the logging yield (accumulated cubic meters of stems during the simulation period) also doubled when logging intensity was doubled.

With the scale-free rule, on the other hand, the logging yield changed very little, at just 2.6 % larger, when intensity – defined as number of independent logging events – was increased to a level that created a 50 % reduction in long-term old-growth cover. The scale-free logging rule, therefore, can be said to generate a forest age class distribution and long-term timber productivity that were quite insensitive to the frequency of individual logging events. However, it produced a contagious mosaic pattern that was very sensitive to logging intensity. An increased logging intensity in this case narrowed the spatial scale range for which the spatial distribution of mosaic elements was fractal, or “scale-free”, by repressing the largest clear-cutting events.

The main reason for this huge sensitivity difference between scale-specific and scale-free logging rules is that the larger frequency of individual logging events in the scale-specific case translated itself directly into a proportionally larger total area of logged 1-pixel stands in any given year, while an increased frequency of scale-free logging events primarily translated itself into a larger number of smaller clear-cuttings (still typically much larger than 1 pixel in the given simulations), without any substantial effect on total, long-term cover in each forest age class. The latter property explains the qualitative differences from right to left in the lower row of Fig. 22.1: increasing the frequency of independent logging events from X/year to, for example, 10X/year decreases the median and range of clear-cutting sizes, but in a manner that maintains the overall percent cover in each age class. This is a very interesting side effect that is not explicitly defined in the logging rule as such, but needs experiments like computer simulations to be discovered and explored (Chap. 21).

Figure 22.2 shows the temporal, long-term aspects of the two logging rules. While the scale-specific rule generates more temporal variability in old-growth cover (as in other age classes) with increasing logging intensity, the result is the opposite for the scale-free rule. The latter series, in particular, shows why it is necessary to run very long series in order to reveal a substantial part of the intrinsic dynamics.

Figure 22.3 illustrates the temporal variability as coefficient of variation (cv), extracted from a larger set of long time series. Interestingly, for the scale-

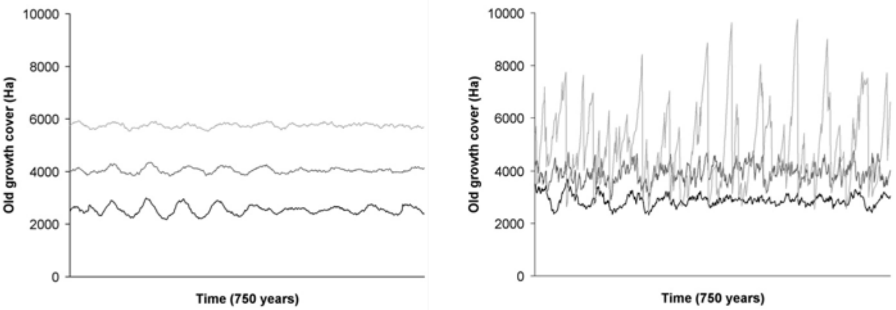


Fig. 22.2. **a** Time series showing total cover of old-growth mountain birch forest, expressed as number of 1-ha pixels (grid cells) inside the model arena, in simulations from a "scale-specific" logging practice (defined in the main text). Initial transients of 500 years (i.e. showing the mosaic "drifting" from a random, homogeneous pattern towards the rule-typical mosaic) have been removed in all series. The three series show that persistent undulations in old-growth forest increase in amplitude when logging intensity is increased from a level maintaining ca. 5500 ha of old-growth (*thin line*) to a level of ca 2500 ha (*thick line*). **b** Similar series, covering approximately the same old-growth cover range, for a scale-free logging practice (see main text) results in the strongest old-growth cover variability for larger cover and decreased logging intensity (*thin line*), i.e. the opposite of the pattern in **a**

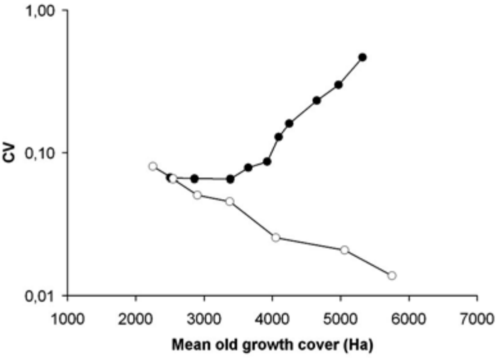


Fig. 22.3. Statistical analysis of the six time series in Fig. 22.2 shows for the scale-specific logging practice (*open circles*) an approximately log-linear (i.e. exponential) decrease in the coefficient of variation (*cv*, standard deviation relative to the mean) as a function of old-growth cover. The scale-free logging practice (*filled circles*) shows a log-linear increase in variability from old-growth cover of 3000–4000 ha and upwards. Thus, decreased logging intensity, which leads to an overall increase in mean old-growth cover, gives a more variable mosaic

specific rule, the cv for old-growth cover series decreases approximately exponentially with increasing cover of old growth, while the scale-free logging rule produces an exponentially increasing cv for old-growth cover above ca. 20–25 % of the total arena. This exponential fit is an emergent property from the complex spatio-temporal dynamics, which needs further theoretical research in order to be understood more explicitly in mathematical and statistical terms.

One practical consequence of these results for sustainable management of northern birch forests is indicated in Fig. 22.4. We have visualized the youngest age classes as white shading, and used spatial snapshots from the same series (but at other points in time) as in the lower row of Fig. 22.1. We have also superimposed some freehand-drawn movement paths mimicking free-ranging sheep preferring to move and forage in open sites and avoiding medium- and old-growth sites. These paths show that the sheep may have better conditions for interpatch commuting between open, high-productive grazing fields in a forest with a relatively fractal distribution of patches of a given class. This conclusion from visual inspection is based on the assumption that sheep, and perhaps also reindeer (cf. Chap. 17), may have problems penetrating the now strongly expanding medium- and old-growth mountain birch forest stands in areas that have not been under long-term use by grazing ungulates. Further research is needed to explore to what extent this is the case. Figure 22.4 illustrates what might be an important aspect of future management of this ecosystem if a holistic approach that considers both grazing potential and forest exploitation is desirable.

So far, we have illustrated the pattern-generating feedback process between forest growth and logging using two rather extreme logging rules. These "idealistic" rules in model terms have been chosen to maximize the qualitative differences between a scale-specific and a scale-free logging policy. However, we can also imagine a modified, scale-free rule, where a given percentage of the potential clear-cutting area is actually logged by choosing pixels randomly within the defined area for a specific logging event, rather than logging 100 % of the defined old-growth site. In this manner, we can obtain a gradual shift from the patterns in the lower row of Fig. 22.1 (100 % of

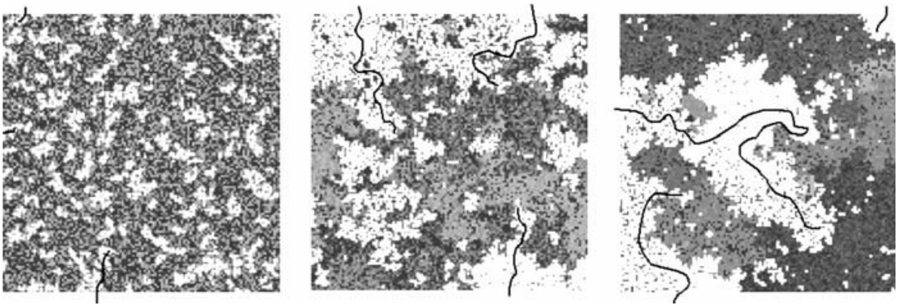


Fig. 22.4. Freehand drawing of virtual paths from grazing ungulates moving in relatively open patches (clear-cuttings and young age classes of birch forest) superimposed on simulation snapshots similar (but not identical) to the series in the lower row of Fig. 22.1, with highest long-term logging intensity in the picture to the *left*. *Paths* indicate that a forest mosaic that is maintained by scale-free logging practice may offer better forest penetration and interpatch commuting opportunities for animals the larger the spatial scale range for fractal (scale-free) mixture of small and large stands

the defined area is logged in each logging event) to something that resembles the upper row in Fig. 22.1 as we reduce the percentage of the pixels that are actually logged in each event. Decreasing the intrasite logging percentage in this respect also increases the overall cover of old growth and reduces the extreme fluctuations in Fig. 22.2b.

This example indicates that a large range of possible logging policies can be imagined, and that any given practice will have profound effects on the mountain birch landscape in qualitative terms in the long term.

22.4 Discussion and Conclusion

The Sámi culture's careful harvesting of individual birch stems more or less spread around the forest (Aikio and Müller-Wille 2002; Chaps. 18 and 23) will have little or no impact on the speed at which mountain birch will probably spread into new areas in the future. This local tradition may represent sufficiently optimal thinning and harvesting in an established subalpine and subarctic forest ecosystem, i.e. where the forest is well established. It will be insufficient, however, to hold back an advancing front of young birch stands spreading over huge areas of currently treeless arctic and in the more thinly forested ecotone along subarctic, subalpine regions, at least under more eutrophic and not too dry conditions. One may doubt that the relatively sparsely populated local communities of people, often using traditional and labour-intensive tools like axes and chainsaws, will be able to hold back anything but a tiny fraction of millions of young birches establishing themselves along an advancing tree-line front every year due to, e.g., climate change, and simultaneously maintain sufficiently a magnitude of open, interconnected grazing areas behind the front. Further, these newly established birch forests can be expected to be significantly denser in their medium- and old-growth phases than existing mountain birch forests, where long-term habitat use through grazing has thinned the understorey, and long-term influence from local tree cuttings may have kept the canopy relatively open, allowing better growth conditions for important food plants for ungulates as a side effect. The local grazing pressure from more free-ranging ungulates can have a profound influence on the forest mosaic dynamics and birch demography inside established mountain birch forests, but this is still an area where much basic research remains to be done before proper predictions about spatio-temporal effects can be put forward for management (Gautestad et al., unpubl. observ.).

By various means other than logging (e.g. strong grazing, fire or even chemical birch killing), one may be able to maintain some degree of openness behind the advancing front of otherwise new and relatively dense mountain birch forest in some areas where this is most critical for local culture and resource exploitation. For example, intentional forest fires have been used extensively in historic times to open new cultural fields (Bleken et al. 2003). Over time, however, even these intensively managed areas will gradually change their floristic, faunistic and ecosystem properties in the direction of similarly culturally maintained fields typical of the lower and southernmost parts of subarctic and subalpine areas of today. However, a proper management policy should aim to make the best out of the situation in the long run in critical areas, based on explicitly defined priorities and goals (see also Chaps. 23–25).

Our model simulations are not primarily meant at this stage to offer detailed management guidelines for these areas. The primary goal has been to illustrate in a phenomenological and conceptual manner how various hypothetical logging rules may have profoundly different qualitative effects on the region's shifting mosaic of grazing fields (see dynamic presentations of simulations in PPT file of CD). We have shown how various simplistic logging rules as a side effect may create qualitatively very different forest structures at the landscape scale in the long term, which in turn may strongly influence other uses and resource potentials of this ecosystem in quantitative terms. Understanding these processes and interactions is crucial when it comes to defining a broad, holistic management regime across traditionally diverse disciplines like forestry and the local cultures related, e.g., to reindeer herding and sheep management in turn. This management regime also needs to be founded on proper conservationist ecological principles in order to defend itself as a sustainable policy.

References

Aikio MS, Müller-Wille L (2002) Living at the timberline – the Sámi and the mountain birch forests in northernmost Europe. Finn For Res Inst Res Pap 862:40–56

Bleken E, Mysterud I, Mysterud I (2003) Forest fire and environmental management: a technical report on forest fire as an ecological factor. Contracted report. Directorate for Fire and Explosion Prevention and Department of Biology, University of Oslo

Franklin J, Woodcock CE (1997) Multiscale vegetation data for the mountains of southern California: spatial and categorical resolution. In: Quattrochi DA, Goodchild MF (eds) Scale in remote sensing and GIS. Lewis, Boca Raton, pp 141–168

Hay GJ, Marceau DJ, Dubé P, Bouchard A (2001) A multiscale framework for landscape analysis: object-specific analysis and upscaling. Landscape Ecol 16:471–490

Pickett STA, White PS (eds) (1985) The ecology of natural disturbance and patch dynamics. Academic Press, Orlando

Reice SR (1994) Nonequilibrium determinants of biological community structure. Am Sci 82:424–435

23 Managing the Nordic Mountain Birch Ecosystem: Local Communities and the State in Finland's Forestry

L. Müller-Wille, M.S. Aikio and V. Luhta

23.1 Introduction: Resource for Wood and Energy

Issues surrounding the management of sustainable resource utilization in ecosystems have been at the forefront of the discussion over the development of environmentally sound policies (cf. Hukkinen 1999). At the core of these discussions are the human–environmental interactions that have an altering effect on the physical conditions of ecosystems, such as carrying capacity and biodiversity. Concepts such as eco-efficiency in institutional environmental management have aimed at reducing and restraining human impact globally, however, often neglecting the intricate material relations humans have with their environment locally. It is therefore of paramount importance to realize that "…environmental management will fail without the individual understanding of local ecosystems, which requires local institutions with clear connections to the material world." (Hukkinen 2001, p. 312).

It is in this context that this chapter advances, first, the assessment of present local management practices in the mountain birch ecosystem (cf. Chap. 18) and, second, the presentation of scenarios to cope with future developments following established approaches (cf. Bruun et al. 2002). The focus is the development of different institutional management options in decision-making for the utilization of the mountain birch forests in northernmost Europe, a specific and spatially limited ecosystem utilized by local permanent residents for energy and materials (cf. Chaps. 3 and 17; Thannheiser and Müller-Wille 2003). The geographical and socio-cultural focus is put on Sápmi and Sámi and Finnish communities in northernmost Finland, the municipalities of Ohcejohka (Utsjoki) and Anár (Inari).

Since time immemorial, humans, who had moved into the northern, subarctic and boreal fringes of specific tree species such as spruce, pine, birch, aspen or willow, have relied strongly on these forests for energy and materials. In this respect, the altitudinal and latitudinal expanses of the mountain birch

---

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

ecosystem in northernmost Europe have sustained human occupancy for millennia by providing wood resources, fuelling locally emerging economic activities such as reindeer herding, hunting, fishing and gathering for a limited human population. In this sense, birch wood was a major element in securing livelihood through energy and materials for heat, shelter and tools since the beginning of human occupancy.

The extensive reliance on this specific and other natural resources required the development of precise and exact environmental knowledge which allowed the original local populations, here the Sámi (Lehtola 2002), to manage the sustainability of the ecosystem they lived in (cf. Aikio and Müller-Wille 2002). The level and spatial concentration of birch utilization have always been dependent on the availability and reproduction of this species. Extensive use or even depletion of birch in some specific geographic areas has caused shifts in human occupancy. This provided the recuperation of the vegetation base. The northern birch forests are quite sensitive and susceptible to both environmental change and human impact.

The premises for the internally evolved system of wood utilization and its related management of "check and balances" were altered within the mountain birch system when other external interests and users extended into these regions from south to north during the last two or three centuries. Supported and encouraged by the emerging structure of central states, for example Sweden, these interests began with the extension of agricultural colonization and public administration which led to an increased immigration of "new settlers". Later on this was expanded by the rapid development of infrastructure and exploitation of resources such as lumber, minerals and water for energy during the 20th century. Other elements have been added since the 1960s, through the emergence of modern large-scale tourism and recreation. These changes have resulted in larger permanent populations and service facilities in central places as well as in an increase in ephemeral tourists several times more numerous than the local residents themselves (cf. Chap. 15).

These developments have created pressure and stress on these northern areas and, in particular, on the mountain birch ecosystem. Affiliated with these changes, local demands have increased considerably for wood, specifically for birch as prime firewood and utility wood for implements and handicraft. Questions have arisen concerning the "sustainable" amounts of birch wood that could be "safely" taken from the forests without having an impact on the ecosystem. Local and public interests in this specific wood resource differed and conflicted with respect to its management and sustainability. A divergence of opinions was expressed in the interviews conducted. People and institutions had different ideas about future contingencies safeguarding birch as a resource.

Members of the local Sámi communities have continued to claim their rights of unimpeded access to birch forests for their livelihood and well-being. On the other hand, public authorities such as Metsähallitus (Finnish

Forest and Park Service) in Finland pursued their mandate under the notion of “common wealth” to institute regulatory forest management regimes in the name of both economic imperatives and nature conservation serving primarily national interests along with demands for regional development. In northern Finland, the arena for conflict between local residents, either Sámi or Finns, and national interests was set when state and private commercial forestry industry began to expand gradually but certainly towards the northern timberline during the second half of the 20th century. Locally, as well as nationally, this conflict over the timberline forests has not yet been resolved.

The world’s forests, providing energy, material and in extension food, are a vital resource for humankind. This resource has sustained utilization for a long time by humans whose demands and pressures have increased rapidly, threatening the forests’ viability. Today, to maintain this resource, humankind is challenged to find a revised relationship with forests. The mountain birch forests are not exempt from these challenges. Their primary utilization by humans has been for wood energy, i.e. firewood, although this demand has been substantially complemented and, in some regions, replaced by imported energy sources such as oil, gas and electricity during the last 50 years.

On a global scale, wood energy plays a crucial role in the livelihoods of many peoples around the globe, mainly in developing countries. In 1981, the Food and Agriculture Organization (FAO) predicted a scenario that the world would experience an acute shortage of fuelwood by 2000; however, this assumption was not borne out. Still, there are issues of insufficient management of fuelwood resources, including the scarce availability of reliable figures on labor and production in this energy sector which, in the late 1990s, was “…7 % of the world’s total primary energy consumption” (Trossero 2002, p. 5). In Finland, at the same time, fuelwood consumption stands at 15 % of energy requirements, the same level as in developing countries. Efforts have been made by FAO to develop more efficient tools for fuelwood management by refining the statistics on forest products in order to attain more exact estimates on fuelwood production and consumption (Whiteman et al. 2002).

This chapter discusses primarily the questions of local utilization – production and consumption – and the institutional management of birch wood as a source for either energy or materials. This study is based on interviews with members of local Sámi and Finnish communities and officials of Finnish authorities. The research showed that exact figures on birch production and consumption were difficult to obtain even at the very local level because a system of reliable reporting does not exist.

23.2 Forests and Wood: Issues of Power and Control

The modern context of ecosystem management consists of many actors and elements. They include socio-cultural, scientific, economic, legal and political dimensions whose interplay shapes the policies that are developed to set the framework for the utilization of specific resources such as forests, a renewable resource. Resource management, in the true sense of the word the "handling" of the environment by human beings, entails both human and ecological considerations whose goals might coincide or conflict. Without renewable resources, sustained livelihood and food security for humankind cannot be attained and maintained. Furthermore, without continuing natural reproduction, the basis for the viability and biodiversity of ecosystems is curtailed. To reconcile both human and ecological needs, manageable measures have to evolve to sustain the environmental systems locally and globally (cf. Hukkinen 1999, 2001). However, such measures derive from human beings who exercise power and control over these ecosystems with the specific resources that are exploited, marketed and used.

Globally, institutions have been developed to deal with holistic and encompassing ecosystem management. The world's forests are the focus of the United Nations Forum on Forests (UNFF) established in 2000. Its formation goes back to the Forest Principles included in Agenda 21 of the Rio Earth Summit of 1992. The principles set forth expound sound practices of management, conservation, biodiversity and sustainable development for forests and prepared the way for global forestry policies for both woodfuel and utility wood.

Upon pressures by various sectors representing disadvantaged forest users, in particular aboriginal peoples such as the Sámi, versus the interests of the multinational commercial forestry industry, the UNFF created the Collaborator Partnership on Forests (CPF) in 2001. It includes international organizations that promote appropriate mechanisms for environmental conservation in conjunction with sustainable levels of resource utilization. This Forum has also identified "major groups" or "stakeholders" who are closely connected with and affected by forest utilization, among them aboriginal peoples. The UNFF has set 2005 as the target date to formulate and negotiate parameters for the legal framework of an international convention on forests including the mountain birch. It remains to be seen whether these efforts strengthen the locally based, traditional management systems serving the expectations of the immediate users. It is certain that these global developments also have a local impact by shaping management practices among the aboriginal Sámi who are well connected with global networks through their own institutions such as the Sámi Council and Sámi Parliaments.

In Finland, to paraphrase a common attitude, "wood means everything" culturally and economically. Forest resources, including birch, have been a driving factor in the Finnish national economy. Schemes for tactical forest planning and management, including the mountain birch, are formulated and implemented by Metsähallitus based on scientific analysis. The use of forests is strictly regulated under laws and ordinances covering both environmental and economic issues (cf. Pykäläinen et al. 1999). Finland's forests belong mainly to private owners in the southern and central parts. The state manages 60 % of forest lands in the northern parts (province of Lapland). These forest resources are utilized optimally to feed the mills of the lucrative pulp and paper industry. However, since the early 1990s, to keep these mills running at their capacity levels, more and more raw lumber had to be imported, mainly from Russia. For example, Lapland's two pulp and paper mills only receive 50 to 60 % of their lumber requirements from this region's forests. Thus the economic sector is not solely sustained by local supplies, rather it draws its requirements from other regions and thus increases the dependence on the northern timberline forests including birch.

23.3 Current Practices and Perceptions of Mountain Birch Utilization

The areas of the mountain birch ecosystem in Finland are located beyond or north of the current reach of industrial or economic forestry. The importance of the mountain birch as a resource to the local residents and partially to the state is predominantly oriented towards the felling of trees for firewood and materials for implements and art. In northernmost Finland, more than 90 % of the mountain birch forest area comprises public lands under the authority of Metsähallitus. The remainder of the forests is shared among individual owners of dispersed woodlots and joint owners of "common forests"; these latter ones also have pine. In this region, the economic output of the mountain birch forests in wood products is minute in comparison to any other forestry sector in Finland. Still, locally it is of considerable cultural and socio-economic importance and value for the livelihood of both Sámi and Finnish residents (cf. Chap. 18).

In northernmost Finland, forest planning and management have remained thorny issues of ownership and control over resource utilization of public lands. This aspect continues to affect the relationship between the Sámi, the recognized aboriginal people under Finland's constitution, and the state. Since the 1990s, this issue has been dealt with by a number of state committees which have proposed political and legal resolutions to Sámi claims (Lehtola 2002). Still, these unresolved claims continue to overshadow the practices of land-use generally and forest management specifically at the local and regional levels.

From time immemorial, the mountain birch ecosystem has been exposed to multiple use through human occupancy. More recently, this pattern of multiple use has expanded rapidly due to the increase in people and the application of technological innovations which all have an effect on the ecological conditions of the forest ecosystem, be it fauna and flora, soils, hydrography or topography (cf. Chaps. 3, 4, 17). The constantly extending multiple use includes, next to the acquisition of wood for energy and materials, reindeer herding (cf. Chap. 19), (sports) hunting and fishing, trapping of ptarmigan, gathering (berries and mushrooms) as well as rapidly expanding tourism and recreation, the latter practically during all seasons (cf. Chaps. 14 and 15). Throughout the area of the mountain birch forests, all these activities are accompanied by an increase in density and extensive mobility of not only animals, for example reindeer, but also people on foot or in vehicles, creating a network of tracks and trails in addition to the constructed infrastructure such as residential areas, roads and facilities (cf. Chap. 24). The pressures and threats to both the physical and human environment are extensive. The authors' research indicates that both local people and public authorities are aware of the impact and give attention to the institutional structures that influence and shape management policies.

These current management practices that function in the mountain birch ecosystem in northernmost Finland are pursued by three categories of actors who carry different weight and influence. These actors are (1) the private owners, either Sámi or Finnish residents who use their own woodlots for either home requirements or some limited economic returns, (2) the private or semi-public forestry industry using public lands under concessions and licenses, and (3) the governmental authorities such as Metsähallitus and Metsäkeskus (Finnish Forest Centre) under the Ministry of Agriculture and Forestry as the "guardians" of public forest lands including protected area. In Finland, all these actors fall under the legal and regulated system of forest planning and management set out in the Finnish Forest Act which was last amended in 1996 and extended to include also all mountain birch forests for which now the same rules apply as for pine forests.

According to satellite image analysis conducted by Metsähallitus between 1996 and 2000, the area covered by mountain birch forests in northernmost Finland amounts to 6650 km^2, with roughly 50 % being pure mountain birch areas. This is about 25 % of the total area that contains mainly pine stands in the southern tiers. The standing volume of the mountain birch forests based on crown coverage is circa 7.4 million m^3, with an average growing stock between 11 and 26 m^3/ha depending on the density of trees (Mattson 2002). For example, in the municipality of Ohcejohka, the figures were 0.93 million m^3 or 28 m^3/ha; this is considered suitable for felling, although minimum figures are not suggested by Metsähallitus for the threshold level at which birch forests can sustain felling for firewood and utility wood. The household and cabin survey conducted by the authors in Ohcejohka between 2000 and 2002 indicates in its extrapolation that about 10,000 m^3 of birch wood is felled annually in this municipality alone. This figure is much higher than the estimate for annual firewood consumption, which stood between 5200 and 6200 m^3, thus actually showing a surplus for storage or sales outside the municipality, mainly to Norway. This amount felled would mean an annual average cut of 0.06 m^3/ha. These figures are minimal when looking at the whole area. Wood felling is not evenly spread spatially for obvious ecological and practical reasons, but rather highly concentrated in areas of prime and mature birch stands. In this respect, the application of management principles that take into account local environmental knowledge such as age of mature trees is therefore crucial to the sustainability of this level of use.

23.3.1 Management and Production of Private Birch Woodlots

Management practices of privately owned birch forest lots for firewood and utility wood have a long tradition among the Sámi and Finnish residents in northernmost Finland. In particular, Sámi residents have relied on culturally defined knowledge passed down from generation to generation. For local residents, mainly Sámi, these management practices were and are still today rooted in the socio-cultural context and in the assumption that local residents have the right to fell trees for home consumption anywhere (in Finnish "puuoikeus"). This assumed right has gradually been curtailed by ordinances decreed by authorities based on the assessment that excessive exploitation and consumption have existed locally since the early 20th century. Local residents have criticized this interpretation which has led to a rigorous fee and license system for access to felling birch trees on public lands. Local users, particularly owners of woodlots, have stated that they are fully capable of evaluating forest conditions for the purpose of tree felling. However, it is also recognized that an overseeing institution is useful to alleviate disagreements and conflicts and allow fair access to and distribution of the available wood resources in a sustainable manner.

As mentioned above, the economic returns of birch wood utilization are minute compared to other sectors in the local economy, which is maintained by a strong service sector supported by the national network of public funding. Some figures for Ohcejohka, the northernmost municipality and only one with a Sámi majority in Finland, provide indicators of the value of this limited sector. In 2002, this municipality had 600 residential units with a population of 1350; most of the units are heated by oil or electricity today. In the 1980s, roughly one third still relied solely on wood and another third used wood as a backup (Mattson 2002). The average consumption of birch dropped from about 50 m^3 for a farmstead (including barns, workshop and sauna) in the early 1900s to 10 m^3 for a wood-heated residence (with sauna) in 2002. This puts the current total annual firewood requirement for home consumption in the municipality between 4000 and 5000 m^3. In addition, in 2002, there were 400 recreational cabins of which 60 % are used on a regular basis; their annual firewood use was on average roughly around 3 m^3 per cabin, i.e. an additional 1200 m^3 in firewood required locally. Thus the estimated consumption of firewood in the municipality is between 5200 and 6200 m^3 annually. On the other hand, the interviews indicated that around 10,000 m^3 of wood is taken from private woodlots or state forests annually.

Based on the standing volume calculated by Mattson (2002), an annual growth of 43,000 m^3 of birch can be extrapolated in Ohcejohka. The annual take would thus represent between 12 and 23 %. To most interviewees this is a sustainable yield if a 60- to 80-year reproduction cycle for "firewood" stands is taken into account. Most of the locally used birch firewood is taken from private woodlands; however, the standing volumes of these individual woodlots are not known. The assessment of the standing volume and the decision how many birch trees are felled each year rest with the eyes, minds and hands of the individual owners managing the lots according to local knowledge and strategies.

In 2003, in addition to cuts on private woodlots, local residents obtained licenses from Metsähallitus to fell trees on state land. Metsähallitus decides on the location, area and the maximum firewood volume that can be taken. The fee was EUR 63.00 for 1 m^3 of birch trunks; labor and transport were at the expense of the user. In comparison, 1 m^3 of felled birch trunks could be obtained for EUR 33 privately delivered to the home. In 2002, the calculated annual expense for firewood for one residence (10 m^3) was thus between EUR 330 and 630 compared with circa EUR 2000 annually for heating with oil or electricity.

23.3.2 Management and Production of Public Birch Forests

In Finland, the management of forests on public lands is under the authority of Metsähallitus and ultimately the Ministry of Agriculture and Forestry. Locally, the Forestry Inspector is the official to ensure that the Forest Law covering both public and private forests is respected and that the established forest policies and plans are implemented. Civic organizations such as the Regional Forest Committee or the Forest Management Association represent local forest owners and users and can advise on issues of local forestry practices. Recently, the scope of Metsähallitus' tasks has changed from a purely public authority pursuing the advancement of the forestry industry to a government organization that was mandated to show public responsibility but also economic profits. This reorientation has also had an influence on its attitudes toward the utilization of mountain birch forests.

As of 1993, the diverse range of Metsähallitus' mandate has included, it seems, competing and even contradicting tasks to cope with the management of public lands. The range is manifold, trying to integrate the demands for (1) nature conservation, (2) protected ecological regions, (3) public participation,

(4) incorporation of local knowledge, and, last but not least, (5) management of profitable, but sustainable forest use. In this context, public participation in policy development, if not implementation and execution, can be identified as a political move with an emerging "soft" or "human" approach by public authorities to define their role as appearing more accountable to citizens (= local residents) for their land-use practices. According to official statements, this apparently has been achieved by conducting public hearings and encouraging public participation, establishing advisory councils on natural resource development, and specifically designing strategic forest planning and management of all tree species through a participatory approach to decision-making (Kangas et al. 1996; Pykäläinen et al. 1999).

Today, Metsähallitus is clearly dedicated to a multiple use of state forests under its jurisdiction in northern Finland. Examples of uses are the control of private access for wood cutting through specific individually issued licences for selected locations, for amounts of trees felled, or even for single birch trees with burls for special purposes such as handicraft; the granting of concessions to industrial forest companies for large-scale wood exploitation; the selling or leasing of plots for the construction of recreational cabins with regulated use of firewood; or building of facilities for nature tourism and other activities by themselves or by private initiatives under license. Throughout Finland, a more recent development is the integration of waste and brush wood from felled areas or sawdust and chips from mills. In northernmost Finland, mainly pine and spruce but more and more birch are included in the woodfuel chain to produce energy for public heating systems. For example, in 2001, under a license of the Ministry of Environment, in Ivalo (4000 inhabitants) 19,000 m^3 of such "waste" wood was fed into the newly built facility generating 3.2 mW of energy for 38 buildings (information provided by the Metsähallitus office in Ivalo, 2002).

Finland, as mentioned above, derives 15 % of its energy requirements from wood. Still, the increased availability of different energy sources has generally resulted in an overall decrease in the demand for firewood during the last few decades. In 1970, 7.5 million m^3 of firewood (pine, spruce, birch) was burnt. This figure dropped to less than 5 million m^3 in 1997 and represents less than 9 % of the total wood felled. Similar figures are, in fact, difficult to extrapolate for the northern mountain birch forests. It is calculated that 210,000 m^3 of wood is felled annually in the municipality of Anár: 150,000 m^3 on state land and 60,000 m^3 on private land. Of the amount taken from public lands under the Metsähallitus fee system, only 2 % or 3000 m^3 was birch, which was sold for a total of EUR 17,000 to private citizens or firewood entrepreneurs, certainly not a lucrative item for a profit-oriented state institution (information provided by the municipal office in Ivalo, 2002).

Still, it is projected that the demands for firewood, especially birch, will increase in the near future, not necessarily due to the need to heat one's house or cabin, but rather being embedded in the aesthetics of using wood as an expression of the link with nature. This is particularly true for places in northern Norway where a smaller volume of birch stands exists, but many more wood users, mainly cabin owners (cf. Chaps. 15, 16, 24). Since the 1990s, firewood entrepreneurs, who also import raw birch wood from Russia, and, in particular, Metsähallitus have reacted to this demand to export firewood to Norway. Another reaction to these circumstances, partly caused by increased oil and gas prices, is the involvement of Metsähallitus and Metsäkeskus in a large-scale bioenergy program in northernmost Finland that includes a firewood marketing centre for private supplies. In 2002, its volume was 25,000 m^3 of firewood and it is expected to grow to 100,000 m^3 annually once more and more forest lands, including prime mountain birch forests, are brought into the bioenergy plan.

These figures indicate that still local production of wood from public mountain birch forests is quite minute. However, its public management is quite complex and has caused disagreements and criticism by local residents who have voiced their concerns over the appropriateness of fairly rigid rules to manage this resource.

23.3.3 Perception and Assessment of Mountain Birch Forest Management

The analysis of the interviews with local residents shows that the current management policies of forest use by Metsähallitus require scrutiny. Local residents expect more transparency. Still, about 40 to 50 % of the interviewees said that, at this time, Metsähallitus was the "best organization to handle the use of birch forests and other forests because of its long-term experience to manage public lands and its forests." Furthermore, it was stressed that, in any case, an umbrella institution is needed within the realm of multiple land-use interests and practices to avoid anarchy and chaos. On the other hand, 22 % of the interviewees issued strong criticism of Metsähallitus and would like to see another organization of a more democratic and transparent nature that would involve local representation or even community associations or co-operatives, a kind of co-management regime. This would guarantee that issues of and decisions about resource utilization are handled directly in the region.

There is a strong opinion, particularly among the Sámi, that stated "the closer decision-making and management is to local people, the better it is for both people and the environment" (cf. Chap. 18). In the Sámi communities, a difference was detected between the older and younger generations with respect to resource management; the older people, still very closely attached to the land, were for more direct control such as the Sámi siida system or the Sámi Parliament, whereas the younger generation showed less interest in the resources locally, but rather combined both internal and external opportunities. Furthermore, in comparison with the larger population centers, people in dispersed settlements were more inclined towards local control or to a co-management regime based on partnership.

The forest management practices by Metsähallitus were seen only by 20 % of the interviewees as being satisfactory. People indicated that the permit and fee system with respect to the use of birch had gone too far, in particular charging a fee for individual trees needed for artwork. According to these local users, any wood for home consumption (residence, cabin, sauna), camp fires during outings and utility (tools, handicraft) should be allowed to be taken by any permanent resident without a special license, particularly since the amounts of wood required locally are minimal (cf. Chap. 18).

There is a clear difference in birch utilization between public and private forests. Whereas birch on public lands is subject to strict rules limiting the cut, it seems that some private owners who participate in the marketing of firewood aim at the maximization of economic return (cf. Chap. 16); thus the management of the resource is short term and often without detailed planning. This is in contrast to Sámi users who, generally, fell birch for home consumption guided by long-term planning based on intimate knowledge of the resource (cf. Chap. 18).

In the 1990s, in northernmost Finland, a shift was noticed in individual and public opinion concerning forest management. Earlier, Metsähallitus was seen as exploiting forest resources excessively; however, during the last few years, users of private woodlots and owners of the common forests have also been identified as pushing the limits of sustainable forestry. Still, Metsähallitus as the most visible actor in the northern landscape has an image that "the State will cut as much as it wants to anyway". This is clearly shown by the state's strategic forest plans intended to push the felling of pine as close to the tree line as possible and economically feasible. It is understood that the reproduction cycles vary between 100 and 200 years and that the return on productivity is minimal in comparison with forests in the south.

Some other critical references were made with respect to Metsähallitus' birch policies which could lead to excessive use due to market demands. Some interviewees also stressed the point that "one should not fell more trees than the land can provide" because the birch forests hold aesthetic, socio-cultural, economic and ecological values. Most of the users had expectations for the continued utilization of birch forests for firewood and utility wood rather than the expansion of cutting for raw lumber (here mainly pine) to feed pulp and paper mills, which would also necessitate and increase the use of heavy machinery.

The interviews provided a rather diversified perception and assessment of current birch forest management by the local population. Furthermore, when asked for projections of where the utilization of mountain birch would lead in the future and under what circumstances, the answers were as diverse as ever. The issues raised hovered around institutions, decision-making, power and control, rather than the amounts of birch that could feasibly be taken under generally accepted criteria for sustainability. Dealing with resource utilization and its management was definitely seen as a political problem in which environmental, cultural and socio-economic aspects also played a role.

23.4 The Mountain Birch – A Resource in the Future?

The future expectations related to birch and the utilization of birch forests are overwhelmingly congruent among the local residents. Maintaining the birch forests for continued use for future generations is a definite goal for practically all residents. In this respect, an increase in the size of birch forests and the recovery of areas destroyed by an epidemic in the 1960s close to the tree line (cf. Chap. 12) are seen as a welcome and very positive development. Furthermore, reindeer herders stressed that birch is crucial for herd management and thus needs to be sustained as a local resource for both animals and people (cf. Chap. 19). People stressed that such needs are identified more easily from the inside than from the outside where, at this point, most of the decisions concerning forests are made. There was also a clear indication that the overall value of birch culturally and economically is still misunderstood and underestimated by the public authorities, which only 40 years ago regarded birch as impeding the growth and expansion of pine and thus needed to be weeded out. Does then the current management regime cope appropriately with this particular resource?

From the research conducted, it seems apparent that, in social and political terms, the management of mountain birch forests underlies a disjointed process which is very much shaped by the dichotomy between inside and outside, center and periphery, private and public as well as encounters of cultures. The many issues of concern touch upon land rights and ownership, access to and control of resources and the acceptance of management practices that rest on local knowledge. Furthermore, quite often, local and public (= national) interests, the latter one increasingly influenced and shaped by processes of globalization, are juxtaposed in their interpretation of environmental conditions such as climatic change, reproduction and biodiversity and philosophies of livelihood, socio-economic development and well-being. These divergent expectations are difficult to reconcile if the willingness to negotiate a revised social contract among the sections in society does not exist.

One way of coping with irreconcilable situations and contingencies is to construct scenarios for possible future developments, even in cases of specific resources such as aquaculture of rainbow trout in the Finnish Archipelago Sea (Bruun et al. 2002). This can be done with the mountain birch as well. Opinions about what kind of institutional management system would work and be most suitable and acceptable varied considerably among local residents, entrepreneurs and forest officials. Three scenarios emerged when future considerations of the sustainability of the mountain birch forest as a resource were discussed. All respondents were asked to include in their statements and reflections environmental, cultural, socio-economic and political aspects. The emphasis here was on institutional adaptation and change and not on levels of production and related economic returns. Generally, the respondents were in agreement that the current amounts of wood taken from the mountain birch ecosystem were sustainable; however, they could be increased under carefully refined management policies and practices (but cf. Chap. 22). All three scenarios mentioned would benefit from a more transparent flow of information providing, for example, for the dissemination of research findings at all levels and for instruction of local knowledge and resource management in schools.

The scenarios requiring institutional change or continuing stability mentioned by interviewees included (1) complete local control through civic associations of owners and users in possible conjunction with Sámi authorities such as the Sámi Parliament or even the municipal administration; (2) a co-management regime based on partnership bringing together, on an equal footing, all the actors discussed above and fashioned, for example, upon Canada's Model Forest Program; and (3) the continuance of public authority as it exists today with public consultation but grounded in centralized national policies that accept variations among regions and ecosystems.

In our opinion, the future development plans for continued utilization of the mountain birch ecosystem need to take into account the diversity of approaches and attitudes. Thus a more holistic and encompassing approach needs to emerge. From our research it seems clear that local owners and users need to be decisive and equal partners in the decision-making process and the implementation of management policies (cf. Chap. 18). Furthermore, environmental conditions need to be studied in a more transparent and participatory way and the results weighed carefully before they are applied as arguments for political decisions on access and production limits. Far too often the knowledge of local users has been bypassed and ignored. It is at the local level that the integrity of human and physical dimensions of an ecosystem is lived and maintained. This is not to say that the local level is isolated from the global dimension; rather the local perspective sharpens the focus of lenses through which global developments are viewed and integrated.

Acknowledgements. The research was funded by the European Union Research Commission under the project HIBECO 2000–2003. The authors are grateful to the local experts and colleagues in Workpackage 1 (Hamburg University, Germany) led by Dietbert Thannheiser. The authors thank Linna Weber Müller-Wille for editing the English text.

References

Aikio MS, Müller-Wille L (2002) Living at the timberline – the Sámi and the mountain birch forests in northernmost Europe. Finn For Res Inst Res Pap 862:40–56

Bruun H, Hukkinen J, Eklund E (2002) Scenarios for coping with contingency: the case of aquaculture in the Finnish Archipelago Sea. Tech Forecast Social Change 69:107–217

Hukkinen J (1999) Institutions of environmental management. Constructing mental models and sustainability. Routledge, London

Hukkinen J (2001) Eco-efficiency as abandonment of nature. Ecol Econ 38:311–315

Kangas J, Loikkanen T, Pukkula T, Pykäläinen J (1996) A participatory approach to tactical forest planning. Acta For Fenn 251:1–24

Lehtola V-P (2002) The Sámi people – traditions in transition (translated by L. Weber Müller-Wille). Kustannus-Puntsi, Aanaar-Inari

Mattson J (2002) Use of northernmost open forests in the European north by Sámi people in Utsjoki, Finland. Finn For Res Inst Res Pap 862:125

Pykäläinen J, Kangas J, Loikkanen T (1999) Interactive decision analysis in participatory strategic forest planning: experiences from state owned boreal forests. J For Econ 5:341–364

Thannheiser D, Müller-Wille L (eds) (2003) Human interactions with the mountain birch forest ecosystem in northern Fennoscandia. Hamburger Vegetationsgeogr Mitt 17:43–65

Trossero M (2002) Wood energy: the way ahead. Unasylva 211(53):3–12

Whiteman A, Broadhead J, Bahdon J (2002) The revision of woodfuel estimates in FOA-STAT. Unasylva 211(53):41–45

24 Policies and Developing Plans Towards Sustainability of Mountain Birch Ecosystems in Scandinavia

L. Bäck, B. Solberg, H. Tömmervik and F.E. Wielgolaski

24.1 Introduction

For at least 8000 years, the northern parts of Scandinavia have been inhabited by the Sámi people. Up until the end of the 16th century, they made a living from hunting and fishing. Each local Sámi community made its living from a well-defined area the size of which was directly correlated with the number of inhabitants of the village (Kvenangen 1996).

Taxation demands of the nation-state as well as the need to provide for an increased population demanded a more stable income and the Sámi people turned to an intensive form of reindeer herding at the beginning of the 17th century. The intensive reindeer herding was then in turn the reason why the Sámi people became nomadic, i.e. they moved with their herds between different pastures according to the changes of the seasons. In Sweden, the Sámi people moved in springtime with their herds from the winter pastures in the forest areas to the high mountain areas on the border between Norway and Sweden, where the herd stayed until autumn when they were moved back to the forest areas in the east. Therefore, local Sámi communities were formed in areas that were only 10 to 50 km wide but up to 300 to 400 km long in an east-westerly direction. In Norway, the distance was shorter between the winter pastures by the coast and the summer pastures by the Swedish border. Since the Sámi people, in addition to wild reindeers, also kept tame reindeers grazing around their settlements, these areas became comparatively worn down. The Sámi people also used the nearby birch forests as a source of firewood and building material (see Chaps. 18 and 23).

During the last 50 years, reindeer herding has been restructured and rationalised. Increasing motorisation with snow scooters, helicopters, etc. in combination with new stretches of roads in the mountain region have made it possible for the majority of the Sámi people to live permanently in larger communities. An extensive form of reindeer herding is developing where the

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

reindeer graze freely over vast areas under the supervision of only a few reindeer herdsmen. To facilitate the work of the Sámi people, fencing has been put up between the villages; this has caused increased wear on the vegetation closest to these fences. Even though the Nordic mountain birch is still used for firewood and construction material, the out-take is smaller in comparison with the time before the Second World War (cf. Chap. 16). To a lesser extent the wood from the mountain birch tree forest has also been used as raw material for handicraft.

Very large fluctuations can be noted in the number of reindeer in northern Scandinavia from around 1850 until today, while the variations over time are considerably smaller further south in the region (cf. Chap. 11; Bäck et al. 1992). During one or several hard winters, the number of reindeer can suddenly be halved and it normally takes 25–30 years to rebuild the reindeer herd to an economically viable size. The impact of reindeer on vegetation through grazing and trampling varies of course with the number of animals (Emanuelsson 1987; Chaps. 4 and 17).

From the 17th century Norwegian and Swedish settlers coming from the south started to establish themselves as farmers in the reindeer pasture areas. This colonisation continued until the middle of the 20th century. The settlers mainly farmed cattle, sheep and goats but also hunted and fished. The forest was mainly used as grazing grounds, but it was also a source of firewood and construction material. The mountain birch forest continued to be used for summer browsing of cows, sheep and goats throughout the 19th century and at the beginning of the 20th century by farmers living both east and west of the Scandinavian mountain chain (Bryn and Daugstad 2001). In the *Empetrum*-lichen-type forests, especially in the forest-tundra ecotone, overgrazing by reindeer and sheep has been a problem during the last decades (see Chaps. 11 and 17; Gaare and Tømmervik 2000; Tømmervik 2000), and in Iceland overgrazing by sheep has caused "desertification" of large areas of different vegetation types over the centuries (Aradottir and Arnalds 2001). However, in the last 50 years, the number of cows, sheep and goats within the birch forest area has generally decreased significantly, particularly in Norway and Sweden. The situation in Finland is somewhat similar (cf. Chap. 23).

24.2 Suggestions for Sustainable Reindeer Management

Too strong grazing densities by reindeer are detrimental for recovery of winter grazing areas, but moderate grazing may improve growth (see Chap. 11). Management decisions (see Chap. 19) should be based on detailed information on local conditions (soil fertility, climatic conditions, vegetation type, pasture rotation, the condition of lichens in the forests, etc.). The optimal production of the lichen pasture is often found to be when the thickness of the lichen mat is in the range of 2–5 cm (lichen coverage >50 %), similar to about 220–700 g/m^2 of standing biomass (see Chap. 16). The optimal production of the lichen pastures calls for an efficient pasture rotation and simultaneously controlled reduction of grazing pressure.

Studies in Norway show that the carrying capacity varies greatly, but when compared with carcass weights (slaughtering weights and production) it seems that the recommended density for winter grazing areas can be even more than 7–9 $reindeer/km^2$, while there are areas such as Målselv where competition by natural resources and harsh winter conditions has reduced these values to about 1.5–2 $reindeer/km^2$. The recommended density in "year-round districts" should be somewhat between these values (see Chap. 16). Altogether, the yearly production in terms of kilograms per reindeer will be more than 10 kg. In future management schemes most sustainable summer pastures, especially grass- and sedge-dominating bog lands (see Bråthen and Oksanen 2001), should be preferred, since they can compensate and even overcompensate for the grazing damage (cf. Chap. 11; Wegener and Odasz 1997). In contrast, most sensitive areas (establishing young birch stands) should be protected from active herding.

The impacts of any modern activities should be evaluated beforehand. For instance, new electrical power lines or other infrastructures such as roads and cottage villages and hotels will reduce pasture area to a considerable extent (Vistnes and Nellemann 1999), the areas outside these encountering greater grazing pressure than before.

24.3 The Mountain Birch Forest from a Multi-User Perspective

The mountain birch forest in the Scandinavian mountain range contains many different resources and interest in exploiting these resources has gradually increased. As early as the 17th century, findings of ore were made and since then many new mines have been opened, the land cleared and the birch trees around the mines have been used for building material and firewood. With time ore mining was concentrated in a few larger mines where bigger communities have developed (e.g. Kiruna in Sweden, Sulitjelma and Röros in Norway).

The distance and lack of communications left the inner parts of northern Scandinavia relatively underused by different potentially interested parties. These conditions have changed radically over the last 100 years. Even before the end of the 19th century the construction of a railroad from Gällivare to Kiruna in Sweden was initiated to facilitate the export of ore on a large scale to the coast and so was the construction of a railroad between Sulitjelma and

Fauske in Norway. Similarly, the railroad through Röros had a strong impact on the trade through this old mining town.

The railroad built between 1898 and 1902 connecting Kiruna and Narvik had a large impact on the environment. The same thing can be said about the railroad that was built between Ôstersund and Trondheim and between the latter town and Hamar a few years earlier. A major part of the forest growing where the railway lines were laid down was removed partly to be used as firewood and building material, partly to clear the space for the railroad itself, staff housing, etc. The next big change in infrastructure took place in the 1950s when roads were built in the mountain area, e.g. crossing Finnmarksvidda in northern Norway between Kautokeino and Karasjok (see Fig. 17.4, Chap. 17). In 1984 a new road between Kiruna and Narvik was inaugurated. The roadwork caused the felling of trees within a 30-m-wide zone in the birch forest area (Fig. 24.1). Many roads have also had a number of secondary effects; new exits, buildings, golf courses, ski lifts, etc. Naturally, this has had a significant environmental impact. According to calculations, the secondary effects affect areas almost as much as the roadwork itself (Bäck and Jonasson 1998).

Fig. 24.1. Railway and roads in the Nordic mountain birch forests have great environmental impacts. (Photo: L. Bäck)

The improvement in the infrastructure has been a significant reason for the gradual increase in outdoor activities in large parts of the mountain areas over the last 100 years. The expansion of tourism in the northern Lapland Mountains and in the mountains of southern Norway was particularly notable between the mid-1950s and the mid-1970s (e.g. Wielgolaski 1978). Since then, the number of overnight stays in the tourist resorts within the areas has come to a standstill or declined. Simultaneously the number of day visitors and the number of people travelling through the mountains by car have increased. This has had a strong influence on the economy of the Nordic mountain birch ecosystem (cf. Chap. 16). A regional redistribution within the northern Lapland Mountains has also taken place. The number of people who stay in hotels along the roads and hike on the paths close to the hotels and communications corridors has increased (in relative numbers) while the frequency of visitors in the more peripheral areas of the mountains has decreased (in relative numbers). The outdoor life has also lead to some wear on hiking paths, taking of birch-bark, littering, a certain out-take of firewood, etc. (Fig. 24.2). The wear on pathways and their width is in direct correlation with the number of visitors (Bäck and Bäck 1986).

Most of the visitors to the mountain birch forest area in Sweden stay in fairly large hotels owned by private corporations or tourist organisations. The

Fig. 24.2. Outdoor living causes damage on the ground as well as wear on the birch forest due to removal of bark and firewood. (Photo: L. Bäck)

number of weekend houses is relatively small, but seasonal camping has increased over the last 20 years. In Norway, there are few hotels relatively speaking and more private weekend houses, which has led to a more extended settlement. That in turn implies greater removal of firewood from the mountain birch forest for heating in Norway in comparison to Sweden and even Finland (cf. Chap. 23).

The use of terrain vehicles has increased dramatically in the mountain birch forest area since the 1960s. Pathways have been cleared for the increasing amount of snow-scooter traffic in northern Sweden. Terrain vehicles enable rapid access to the more remote mountain areas, but they also contribute to more widespread effects from human activities in the mountain birch forest area (see Chap. 15).

Military training has caused damage to the environment in the mountain birch forests of the inner part of the Norwegian county of Troms and in Hallkavarre in the county of Finnmark (Norberg et al. 1998). This damage is mainly due to off-road traffic by motorbikes, four-wheeled cars, band-wagons and tanks, but also noise and people have disturbed and stressed the wildlife in these environment (cf. Chaps. 15 and 17). Moreover, the introduction of four-wheeled vehicles in reindeer husbandry and in recreation has caused damage and disturbance to the flora and fauna (Norberg et al. 1998; Gaare and Tømmervik 2000). The damage by off-road traffic is often of a linear type and these tracks have caused soil erosion and damage to wet mires, which can damage the living conditions for waders, birds, insects and other animals (Norberg et al. 1998; Rae et al. 1998).

The biggest threat to the reindeer industry and nature in many areas of the mountains is the expansion of hydroelectric power. This expansion started as early as ca. 1910 and has since then affected many waterways. Sizeable dams have been built in the mountains and large areas have been flooded. This has initiated strong discussions with conservationists both in Norway and in Sweden. Even Torneträsk was threatened by the expansion in the 1950s, but widespread protests from researchers from all over the world stopped the exploitation. A number of dams at the sources of the Lule River were built in the 1960s which have changed the ecosystem completely. The same thing happened with the Alta River in the 1980s but at a reduced scale compared to the original plans because of protests.

In certain regions, there has also been a substantial felling of trees in the so-called close mountain forest. That also caused a large extension of the forest roads system. It was a shortage of forest worth felling in the Norrland inland that brought about the threat of large-scale clearing of the mountain forests. The environmental debate during the 1980s resulted in a decline in the clearing of the mountain forest.

At the end of the 20th century, especially during the last decades, the mountain birch forest has changed in its physiognomy and vegetation composition (cf. Chap. 17). These changes are particularly noticeable at lower altitude in valleys and lowlands with meadow forest and in lichen heath forests at the forest line.

Logging and lowering of the water table for cultivation and farming have interfered with the natural growth of meadow forests and biodiversity, especially in the river valleys. Rapid expansion of agricultural land, infrastructure and roads has had an impact on the biodiversity in the "swamp forests" dominated by birch and willows in the river valleys (Werth 2001). In the valleys also dense spruce plantations, which were planted after World War II, caused problems concerning biodiversity, access and migration for animals and people (Werth 2001). On the other hand, as a result of the abandonment of agricultural fields, a significant regrowth of forests has occurred, which has led to reduced biodiversity of species adapted to a semi-natural Sámi landscape and agricultural landscape.

In summary, the gradual increase in pressure on the ecosystem results in an impact on the vegetation in the area. It has lead to a decrease in the forest area and damage to the mountain birch forest area.

24.4 The Human View on Mountain Nature

The Sámi people generally live in harmony with nature. They safeguard natural resources to ensure a sustainable development. In principle, this is also valid for other permanent residents in the area who are dependent on nature. The people making the decisions regarding exploitation of the mountain resources such as hydroelectric power, mining, felling of trees, etc. generally live outside the mountain birch forest area and look at the mountain region from a purely economical point of view, which can easily lead to overexploitation (Bäck et al. 1989). For example, the need to preserve the mountain birch forest is of minor importance to those interested parties. More interesting then is the question of how the large number of temporary visitors, i.e. tourists, look at the mountain birch forest. During the last 25 years, a number of studies have been executed through questionnaires and interviews, with the aim of studying outdoor life and its changes in the northern Lapland Mountains (Bäck and Bäck 1986; Bäck 2002; Chap. 15).

Some of the questions regarded the motives for travelling to the northern Lapland Mountains. The visitors in summertime have foremost stated the beautiful, untouched nature, the clean air and water as the main reasons for coming. Secondary important reasons for the visit have been the good hiking paths and good options for staying overnight within the area. For visitors arriving in the northern Lapland Mountains in wintertime it is the good supply of snow and good terrain for skiing that are most important. When you let the visitors rank the biggest attractions on a scale from 1 to 5, where 5 is the highest, the beauty of the landscape scores 4.8 on average, the clean water and air 4.5, plants and animals 3.9. If you divide the visitors into different categories, you find that the importance of nature is relatively low for people travelling through the area without staying overnight in comparison to the visitors who spend at least one night in the mountains. The longer you stay in the area, the more you appreciate the nature.

Most appreciated are the magnificent views of, for example, high mountains and large lakes. The pathways leading through mountain birch forests are not regarded as beautiful, and the restricted view you have in the forest is noted as one of the reasons for that. The famous Kungsleden (the Royal path) in Sweden stretching north–south through the Lapland Mountains is therefore given a comparatively low attraction value in the surveys carried out. Apart from the views, visitors also appreciate the silence and the opportunity to travel through nature alone or in small groups.

24.5 Visitor Frequency in Nature

In wintertime, the visitors mainly stay close to the hotels and the ski lifts. Even in summertime, the visitors mainly stay in the vicinity of the hotels, i.e. within a hiking distance of 15–30 min. The frequency of hikers rapidly declines with an increasing distance from the starting point of the hike (cf. Chap. 15). This means that most hikers can be found within the mountain birch area even though this environment is not regarded as as attractive as the mountain above the tree line where the view is unobstructed. On the other hand, most overnights (camping) are spent in the valleys of the birch forest region where wind protection and firewood can be more easily found. Owners of weekend houses and seasonal campers are increasing in numbers. These groups also mainly move about in the vicinity of their overnight places, i.e. often in the mountain birch forest.

Both Sweden and Norway have comparatively well-developed hiking pathway systems with overnight cottages. Between 3000 and 4000 people pass the most-frequented part of Kungsleden every year, although less than 2000 people will hike on most paths. There is also a large group of people hiking off the marked pathways in order to more intensively experience nature (Bäck 2002).

25.6 Different Planning Strategies for Sustainable Development in the Mountains

As early as 1864 in the book, *Man and Nature*, the American Marsh stated that pressure on the ecosystem was increasing (Marsh 1864). In the USA, this led to a growing interest in preserving certain areas and the first national parks were founded. The ideas also spread to Europe. In 1909 around ten national parks were founded in Sweden, most of them in the mountain birch forest areas, for example the national parks of Abisko, Sarek and Stora Sjöfallet. The objective of these national parks has been mainly to protect the nature from human intervention, but there was also a conscious strategy of attracting as many visitors as possible, with the condition that the number of visitors does not surpass the carrying capacity of the specific area. The number of national parks has increased during the last 50 years (see Chap. 15).

As a part of physical community planning, a large number of national parks were established in Sweden in the 1960s, while in Norway only four national parks were founded in 1970, but the numbers and areas have strongly increased more recently. The demands from a clearly sustainability perspective have increased also at the community level. An additional number of planning strategies of interest to the mountain birch forest were introduced in the middle of the 1970s. Large parts of the Scandinavian mountain areas are of national interest for nature conservation and outdoor recreation. In 1976 an extensive mountain inquiry was initiated in Sweden with the aim of defining possible grades of "nature worth" for different areas. This inquiry resulted in a new national park plan for Sweden. In this plan the idea of creating Europe's biggest national park in the Kiruna Mountains was introduced. The principally most interesting aspect of this national park would have been the division into zones following international standards. Some parts would have been heavily protected and others allowed to be subjected to a relatively high degree of exploitation (Bäck and Strömquist 1987). The plans were put on ice after resistance from mainly the local government.

The world is developing towards increased globalisation as well as increased pressure on the ecological system. During the last 30–40 years, it has become more and more obvious that the resources of the world are limited and that sustainability questions have to become the focus of a greater international involvement. Regional planning strategies to establish nature reserves and national strategies to establish national parks have not been sufficient to prevent the pressure on the ecosystem from increasing. Therefore, the question of preservation has been moved on into the international arena.

As a result of increasing globalisation, we have at the end of the 20th century seen new reserves established and conventions sanctioned by the UN organ UNESCO. In the mid-1980s, Torneträsk was appointed as a "MAB" reserve (Man and Biosphere reserve) wherein the society wants to follow the future development. The mountain area around the sources of the Stora (Big) and the Lilla (Small) Lule River was appointed as a World Heritage site for both natural and cultural reasons in 1996. There are only about 20 areas in the whole world with this double world heritage status. This vast mountain area goes under the name of Laponia.

Within the HIBECO project we have investigated whether these new planning instruments have had any significant positive or negative effects on these areas. However, very few of the visitors to Torneträsk know that they are visiting a MAB reserve and fewer still know the rules applicable to the reserve. Very few say that they are visiting the area because of its high international classification. Visitors from southern and middle Europe indicate to a higher degree than the visitors from Sweden that the classification of the area has influenced their choice of travel destination. Relatively few of today's visitors believe that the new status of the areas will attract a rapidly increasing number of visitors within the next couple of years (cf. Chap. 15). However, in a longer perspective, it is probable that the UN classifications will lead to an increase in tourism which in turn can affect the vegetation in these mountain areas. Since tourists are increasingly interested in the preservation of the nature in the area, the best alternative from a sustainable point of view is an increased degree of ecotourism in comparison to other types of land usage, with the exception of the reindeer industry which for thousands of years has been a natural component in this specific area.

24.7 The Need for Scientific Pluralism

The national as well as the international planning of today focuses on achieving sustainable development from an ecological, economical and social point of view. Therefore, the need for a holistic perspective is often discussed as well as the necessity of considering all relevant variables in an integrated analysis. This is obvious when we look at environmental impact assessments (EIA). As early as 1970, environmental impact assessments were demanded in the USA for all major exploitations that could possibly affect the environment. Similar laws were made in the 1970s in several European countries and early on the European Union made an overall decision regarding EIAs. The demands on EIA; before, during and after every type of measure have increased, but there are still many examples of evaluations that have not been performed with a holistic perspective.

Within the Torneträsk area, a holistic EIA was conducted by a few researchers in 1978–1998 regarding the building of road E10 between Norway and Sweden. The road was opened for traffic in September 1984. From this research it can be concluded that visitor frequency is highly dependent on the degree of impact made on the environment. There was a large increase in visitor numbers when the road was opened, but after a couple of years the visitor numbers started to drop notably. Simultaneously, there was a considerable increase in secondary effects after the opening of the road: large parking lots (Fig. 24.3), new ski lifts, a golf-course, hotel complexes, etc. (see Chap. 15). The surveys show that when the collective impact on the environment becomes too significant the interest of people in visiting the area declines (Bäck and Jonasson 1998).

Fig. 24.3. Outdoor activities demand gradually greater areas. Hills are cleared of trees to make way for downhill skiing or alternatively a golf course. (Photo: L. Bäck)

It has become obvious that people look at the mountain forest resource from different perspectives: as an economical resource, as an opportunity to preserve a culture, etc. During the last 100 years, the pressure on the ecological system in the Scandinavian mountains has gradually increased owing to more interested parties wanting to use the resources of the area. The infrastructure with railroads and roads has expanded. The outdoor life within the birch forest region has gradually increased and has led to the construction of more ski slopes, parking lots, hotel complexes, weekend houses, etc. (see Chap. 15). Commercial as well as leisure traffic with terrain vehicles such as snow scooters has increased substantially (cf. Chap. 16), which has often caused damage to and ruts in the vegetation from the vehicles. The clearing of forests and expansion of hydroelectric power have affected the forest resource heavily. The total impact of exploitation on nature in the birch forest region has raised the question of whether we have sustainable development. From a planning perspective, it is of great importance that we not only look at the landscape from a single sector but also use a holistic approach whereby we consider the impact on nature by man from every imaginable perspective.

24.8 Suggestions for Sustainable Forest Management

In order to gather more information about how best to manage the northern mountain birch forest system, we interviewed managers, farmers, reindeer herders, military officers and craft workers (e.g. 'duodji') and against this background propose measures that can lead to more sustainable development within these forests.

Measures such as restrictions (and banning) of motorised traffic for recreation and restrictions on military activity in these forests and environments were proposed by most of the interviewed people in the HIBECO project, in particular that proposed for areas of grass- and sedge-dominating bogs and mires and "wet" forests. Also, thinning activities in the birch forests for better fuelwood production and special production of birch for handicraft ('duodji') production have been proposed by farmers, reindeer herders and craft workers (cf. Chap. 18). However, birch forestry per se preferably should experience only small changes, i.e. in most cases it should remain at a low level. Reduction of planting of spruce in the birch forests in order to prevent degradation of biodiversity and pasture land for reindeer and sheep has been proposed by many of the interviewed people in Målselv (cf. Chap. 16), but there were also positive comments concerning spruce plantations (especially by farmers). Concerning overgrazing, all people interviewed proposed a reduction in the reindeer density, while the sheep density at the present time was not of concern. On the other hand, we have observed that in parts of Målselv the high density of sheep has reduced the lichen coverage (winter pastures for reindeer) in both forests and heaths (Tømmervik 2000).

Up to now, community planning has been based on a "from above perspective" where the local community has a very small possibility of influencing the decisions regarding the mountain birch forest region (Rådelius 2002). Throughout hundreds of years, a clear core–periphery relationship has developed, where the national state in the role of the core takes advantage of the resources in the periphery. Experiences from surveys carried out within the HIBECO project framework as well as those of Rådelius (2002) show that community planning at a higher degree should be founded in a "from below perspective" in order to enable a local feeling of involvement in the process of safeguarding nature and culture in this peripheral part of Europe.

If we want to plan successfully for sustainable development in sensitive mountain areas such as the Scandinavian mountain birch forest, a prerequisite is to take into consideration the perspective of all the interested parties, as well as weighing the possible advantage against the possible damage deriving from different planning strategies.

References

Aradottir AL, Arnalds O (2001) Ecosystem degradation and restoration of birch woodlands in Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris, and Parthenon, New York, pp 293–306

Bäck L (2002) Friluftslivet i norra Lapplandsfjällen (in Swedish). In: YMER 2002, Svenska Sällskapet för Antropologi och Geografi, Motala, pp 152–167

Bäck L, Bäck E (1986) Effects of a road construction – highway 98 between Kiruna and Riksgränsen. Acta Univ Ups Ser C, no 52

Bäck L, Jonasson C (1998) Environmental impact assessments of the highway between Kiruna and Riksgränsen. Forskningsrapp no 109. Kulturgeografiska Institutionen, Uppsala University, Uppsala

Bäck L, Strömquist L (1987) Miljö, naturvård och planeringsstrategier i ett skandinaviskt fjällområde. Fallstudie från Kirunafjällen (in Swedish). UNGI Rapport no 66. Uppsala University Department of Physical Geography, Uppsala

Bäck L, Josefsson M, Strömquist L (1989) Land capability, recreational land-use and conservation strategies in a sensitive mountain environment. A method study from the Kiruna mountains, Sweden. UNGI Rapport no 73, Uppsala

Bäck L, Hedblom, Josefsson M, Rydén A (1992) Reindeer management in conflict and cooperation. A geographic land-use and simulation study. Forskningsrapp no 104. Kulturgeografiska Institutionen, Uppsala University, Uppsala

Bråthen KA, Oksanen J (2001) Reindeer reduce the biomass of preferred vascular plants over the summer: some preferred plants still dominate the community. J Veg Sci 12:473–478

Bryn A, Daugstad K (2001) Summer farming in the subalpine birch forest. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris, and Parthenon, New York, pp 307–315

Emanuelsson U (1987) Human influences on vegetation in the Torneträsk area during the last three centuries. Ecol Bull 38:95–111

Gaare E, Tømmervik H (2000) Overvåking av lavbeiter i Finnmark. [Monitoring of lichen grazing areas in Finnmark.] NINA Oppdragsmelding 638:1–31

Kvenangen PG (1996) Samernas historia. Sameskolstyrelsen (in Swedish). Ykkös Offset, Jokkmokk

Marsh SP (1864) Man and nature. In: Lowenthal D (ed) Physical geography as modified by human action. Reprinted 1965. Harvard University Press, Harvard

Norberg ME, Simons S, Alm T, Greve Alsos I, Palkin Jakobsen N, Lund L (1998) Prosjekt “Revegetering Karasjokfjellet” 1995–1997 (in Norwegian). Avsluttende rapport. Tromura 83

Rådelius C (2002) Självstyre eller självförvaltning? (in Swedish). Rep 57. Institutionen för Industriell Ekonomi och Samhällsvetenskap, Luleå Tekniska Univ

Rae R, Francis I, Strann K-B, Nilsen S (1998) The breeding habitat of broad-billed sandpipers *Limicola falcinellus* in northern Norway, with notes on breeding ecology and biometrics. Wader Study Group Bull 85:51–54

Tømmervik H (2000) Reinbeitekartlegging. Mauken – Blåtind – Fagerfjell. [Monitoring of the reindeer grazing areas in Mauken – Blåtind – Fagerfjell.] NINA Oppdragsmelding 641:1–34

Vistnes I, Nellemann C (1999) Tap av kalvingsland som fölge av forstyrrelse fra hyttefelt og kraftlinjer (in Norwegian). Reindriftsnytt-BoazodoalluúoDDasat 33: 15–19

Wegener C, Odasz AM (1997) Effects of laboratory simulated grazing on biomass of the perennial Arctic grass *Dupontia fisheri* from Svalbard: evidence of overcompensation. Oikos 79:496–502

Werth S (2001) Key factors for epiphytic macrolichen vegetation in deciduous forests of Troms county, northern Norway: human impact, substrate, climate or spatial variation. Cand Sci Thesis, Department of Biology, University of Tromsø, 89 pp

Wielgolaski FE (1978) High mountain resources and their use or conservation in north Europe. In: IUCN (ed) The use of high mountains of the world. Department of Lands Survey, Tussock Grasslands and Mountain Lands Institute, Wellington, New Zealand, pp 83–97

Section 5

Integration and Conclusion

25 The Nordic Mountain Birch Ecosystem – Challenges to Sustainable Management

F.E. WIELGOLASKI, P.S. KARLSSON, S. NEUVONEN, D. THANNHEISER,
H. TØMMERVIK and A.O. GAUTESTAD

25.1 Introduction

From a global perspective, the Nordic mountain birch ecosystem is a unique feature of northwestern Europe (see Chap. 1). Although it may appear rather homogeneous and simple, a closer look reveals striking regional and local variation in numerous characteristics such as geology, soils, climate, plant productivity, species composition and herbivory, as well as in the history and human activities in this area. These differences have been pointed out repeatedly throughout this volume. The variability not only poses a great resource, but also a great challenge to sustainable management of the mountain birch (and adjacent alpine/tundra) ecosystems. From the variability of many characteristics, it is obvious that the critical or problematic issues vary regionally. Consequently, sustainable management principles are likely to differ from area to area. The specific structure and properties of the mountain birch forest allow a subdivision into different vegetational units that are characterized by particular ecological conditions (see Chap. 3), and the human impact on the various forest types can be considerable.

The density of birch forests and the position of forest lines have varied over time (see Chap. 1) owing to variations in climate and in the human exploitation of birch forests, including domestic herbivores. Particularly in recent times, other human activities, such as tourism and pollution, have had impacts on this ecosystem. Another important, natural cause for long-term dynamics in forest density and productivity is the outbreak of major insect herbivores (mainly the autumnal moth, see Chaps. 5, 9, 12). Events where the stems are killed and the forest is rejuvenated, or the forest is killed, have a major impact on all aspects of the forest's biology and socio-economic utilization for many decades. There is thus a potential conflict between the long-term dynamics of the mountain birch forest caused by the natural insect herbivores and human utilization of these ecosystems. The effects from severe

Ecological Studies, Vol. 180
F.E. Wielgolaski (Ed.), P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests

insect outbreaks strongly interact with reindeer husbandry, tourism and the harvesting of wood for fuel and other purposes.

The strongest human impact is probably found in the river valleys in northern Fennoscandia. Logging, lowering of the water table for cultivation and farming have, through time, interfered with the natural growth of meadow forests and the species composition (biodiversity; see Chaps. 2, 3, 17). The expansion of agricultural land and infrastructure, such as roads, which are all common in the river valleys, has thus had the strongest impact on the species composition (both fauna and flora) in the moist and even wet forests dominated by birch and willows. In the valleys as well as in many coastal areas, dense spruce plantations, which occurred particularly after World War II, have also caused problems concerning species composition, access and migration for animals and people. On the other hand, as a result of the abandonment of agricultural fields found in other districts, a significant re-growth of birch forests has occurred (see Chap. 17), which has led to fewer species characteristic of a semi-natural Sámi landscape and to the agricultural landscape. Military training has caused damage to the environment as well as local changes in the biodiversity in the mountain birch forests of the inner parts of the Troms and Finnmark counties in Norway. This damage is mainly due to off-road traffic, e.g. motor bikes, four-wheeled cars (Fig. 25.1), band wagons and tanks, but noise and people have also disturbed and stressed the wildlife in these environments. The introduction of four-wheeled vehicles in reindeer husbandry and in recreation has already caused damage and disturbance to the flora and fauna (cf. Chap. 24). Damage by off-road traffic is often of a linear type and these tracks have caused soil erosion and damage to wet mires, which can damage the living conditions for birds, insects and other animals. In the heath-type forests, especially at the border between forests and treeless areas, overgrazing by reindeer and sheep have also been a problem in the last few decades (cf. Chaps. 4, 10, 11).

In the past, human exploitation of the mountain birch forests has mostly been in harmony with the natural dynamics of this ecosystem, and severe disturbances have in most cases only been local (see Chap. 14). However, in Iceland, since his arrival 11 centuries ago, man has used the often extremely fragile ecosystems in the areas which were originally abundant birch woodlands. Both clear-cuttings of birch and sheep grazing were reasons for the rapid degradation and soil erosion starting soon after the settlement (Aradottir et al. 2001).

Only in one case, outside the study area of the HIBECO project, viz. on the Kola Peninsula, has air pollution from nickel smelters recently influenced the ecosystem in the region comprising also parts of Finland and Norway (Kozlov and Barcan 2000; Tømmervik et al. 2003). Particularly earlier, however, the mining industry, e.g. in the Röros area in mid-Norway, Biedjuvaggi (Kautokeino) and Kirkenes in northern Norway, and the Kiruna area in northern Sweden, caused landscape-wide disturbances of the entire ecosystem. The

Fig. 25.1. Damage to vegetation and soil by off-road traffic. (Photo H. Tømmervik)

increasing numbers of temporary recreational visitors (e.g. using off-road vehicles) may also emphasize latent conflicts with the balance of these ecosystems and with the traditional human utilization of these areas.

25.2 Man and Mountain Birch Forest Interactions in the Perspective of a Changing Climate

There is a general agreement that the global climate is changing (IPPCWG1 2001). Empirical measurements during the last century have provided local evidence supporting this change in northern Fennoscandia (Holmgren and Tjus 1996; Hanssen-Bauer et al. 2000, 2001). A changing climate is nothing new; marked fluctuations in summer climate at decadal and century time scales have repeatedly occurred in this region (Briffa et al. 1990; Aas and Faarlund 2001). Model predictions of the climate 50–100 years from now indicate a number of changes in the climate of northern Fennoscandia (Hanssen-Bauer et al. 2000, 2001; Räisänen et al. 2003). Annual mean temperature is predicted to increase by 1–4 °C, the highest increment is expected in winter and spring and the lowest during summer. Summer cloudiness is expected to increase while diurnal temperature fluctuations are expected to decrease. The yearly minimum is predicted to increase by 4–10 °C and there may be substantial changes regarding precipitation, but the predicted changes vary strongly along coastal–inland gradients (see Chap. 1) and also markedly between different models.

Changing climatic conditions, mainly precipitation and temperature, will have implications for the soil in this area (see Chap. 2). Soil type is strongly dependent on moisture; changes in cloudiness and precipitation are thus likely to result in changed soil types. If soil temperatures increase, a (short-term) increase in nutrient availability may occur (cf. Chaps. 2 and 8). In relatively dry, cold regions of Fennoscandia (as in the northeast and in a few places in the mountains of central Norway) such climate changes may also cause reduction of palsa bogs (cf. Chap. 2; Luoto and Seppälä 2003).

Changes in both climate and soil conditions have implications for many characteristics of the mountain birch forest and its interaction with herbivores and man. More snow during winter may result in a delayed snowmelt in spring in spite of higher temperatures. Secondary effects of a delayed snowmelt are a shortened growing season (Høgda et al. 2001, 2002) and an offset in the phenology of plants (see Chaps. 6 and 7).

Altogether, there are many results from short-term experiments showing clear effects of the temperature climate on many growth-related traits, but it is still uncertain whether these will translate into sustainable increased growth and productivity under a warmer climate (see Chaps. 5 and 8), although there are tendencies for the mountain birch being denser near the tree line (see Chap. 17; Juntunen et al. 2002; Tømmervik et al. 2004), particularly in some moist and nutrient-rich districts (Wielgolaski unpubl.; Leif Ryvarden, pers. comm.). On dry and nutrient-poor soils, temperature is probably not an important limiting factor for long-term productivity. Regarding vegetation composition, changes have been observed over the last 40 years in some districts (see Chaps. 3 and 17). It was observed in the HIBECO project that plant species favoured by higher humidity, for instance the dwarf cornel (*Cornus suecica*), have increased in recent years, while typical heath species such as crowberry (*Empetrum hermaphroditum*), bilberry (*Vaccinium myrtillus*) and reindeer lichens have decreased. There are several potential causes of these changes. Overgrazing by reindeer and increased precipitation and nitrogen deposition may have influenced the vegetation cover. Particularly in autumn and spring a combination of more precipitation and higher temperatures may cause wet snow in periods, resulting in ice crusts, which of course are difficult for animals such as reindeer to penetrate. The ice crusts and soaking wet soil will also cause many reindeer lichens to die, probably because of a lack of oxygen to the plants (Crawford 2000; Wielgolaski 2001). This may cause more soil to have less dense vegetation, which in turn may result in better germination and seedling establishment of many higher plants, for instance mountain birch (Karlsson and Weih 2001), particularly when there is also better soil moisture due to the higher precipitation. The normally dry, sandy soil in lichen heaths is often too dry for germination of new plants. In

Máze, in inner northern Norway, it was found that there has been a strong increment in the birch forest during the last decades, while the fruticose reindeer lichens have decreased (see Chaps. 4 and 17).

Higher annual minimum temperatures are likely to affect the distribution and performance of insect herbivores. The autumnal moth may benefit from warmer winters and severe outbreaks could then be more likely under a warmer climate (see Chaps. 9, 12, 13). Furthermore, warmer winters and summers may also allow new herbivores to invade the mountain birch forests (cf. Whitfield 2003).

Climate change may be one reason why the elevation limit of the mountain birch has increased in recent years (Kullman 2002), but direct anthropogenic impacts, such as a generally lower out-farming intensity (Bryn and Daugstad 2001) and thus reduced browsing particularly by sheep, have also contributed (cf. Chap. 8). An increase in the elevational tree line may be positive for the primary production of an area (Tømmervik et al. 2004; Wielgolaski, unpubl.). However, if the total grazing pressure does not increase in proportion to the expected increase in young-age birch forest at the dynamically expanding fronts of the tree line, the birch forests may eventually be so dense that they become less suitable for grazing during older stages (see Chaps. 17 and 22). This may be especially relevant in some rich and moist areas (i.e. in good summer grazing sites). Ungulate habitat facilitation needs continuous maintenance by a grazing intensity that is kept above the threshold for a sufficiently penetrable forest (cf. Chap. 18), in areas where the forest otherwise would become too dense for sustainable and optimal utilization as a grazing habitat (cf. Chap. 22), unless counteracted by active and extensive thinning and logging practices.

25.3 Considerations for Sustainable Mountain Birch Forest Management

Discussions about 'sustainable management' are closely related to human activities/livelihoods in specified areas and/or ecosystems. When discussing sustainable human utilization of, and management in, the Nordic mountain birch forests, it is important to keep some points in mind. In Iceland, re-vegetation has been difficult after the early destruction of the native birch forest by man's logging and strong sheep grazing (Aradottir et al. 2001). However, the human populations inhabiting the Nordic mountain birch ecosystem have normally occurred in low densities in Fennoscandia. Rarely, if ever, has this ecosystem been the only source of livelihood for humans. Fishing (either ocean or freshwater) has always been an important contribution to the local economy in the area. In Swedish Lapland and in some birch ecosystem districts of northern and mid-highland Norway, the mining industry increased the local population directly or indirectly during the last century, while in Finnish Lapland such developments have played a relatively minor role. Further, during the last century, the human population structure in the area has changed. Traditionally, there was only one major component in the low-density population: the local residents. Now there are two additional, increasing components: summer residents (cottage owners; especially in northern Norway and Finland) and tourists (cf. Chaps. 15 and 24).

In addition to the traditional resident populations, tourism, industry and public authorities cause the current human impact on the mountain birch forest ecosystem. Decisions on the utilization of birch are made by these actors and are hopefully guided by assumed principles of sustainability and keeping a high biodiversity to maintain the integrity of ecosystems in the relationship with humans. Unless limits, supported by both internal and external interests, are set, the mountain birch habitat is threatened. Tourism, probably the fastest growing part of the local economy, as well as the economy of the traditional local inhabitants, are strongly dependent on unspoiled natural environments.

Local knowledge and expertise (from various local residents and from researchers working in the area) are definitely necessary for, and a valuable component of, the planning and decision-making processes as we aim for sustainable management of these northern, sensitive ecosystems. One way to accomplish a better sustainability in each specific area may be to decentralize decision-making, e.g. with respect to management and utilization plans of the areas, and to use local expertise (both local residents and scientists) in this planning. Steps in this direction have already been taken, for example, in Finnish Lapland. Metsähallitus (Finnish Forest and Park Service) has used ‘participatory planning’ when preparing management and use plans for wilderness areas. A second way may be to emphasize the information flow from the local residents, modified when appropriate by researchers, to a wider audience, including decision-makers.

The main scientific findings of the HIBECO project related to the sustainable management of the northern mountain birch ecosystems are summarized in many of the chapters of this volume. One method used in the HIBECO project to gather information on how to manage the northern mountain birch forest system was to interview managers, farmers, reindeer herders, military officers and craft workers (cf. Chaps. 18, 23, 24). This information has been used together with results from fieldwork within the HIBECO project and earlier scientific studies for suggestions given in chapters of this volume, which hopefully will lead to a more sustainable development within these forests, i.e. use of the forests without destruction in the long run (see Chaps. 21–24).

Measures like restrictions (and banning) of motorized traffic for recreation and restriction of military activity in these forests and environments have been proposed by most of the people interviewed; in particular, restrictions for the disturbance of sensitive grass- and sedge-dominating bogs and mires and wet forests (see Chap. 24). In addition, thinning activities in the birch forests for better firewood production and special production of birch for handicraft production have been proposed by farmers, reindeer herders and craft workers (cf. Chap. 18). A reduction in the planting of spruce in the birch forests is one way to prevent degradation of pasture land for reindeer and sheep and a reduced number of species in the forests. Therefore, this had been proposed by many of the questioned people in Målselv in the county of Troms in northern Norway (see Chap. 24), but there were also positive comments concerning spruce plantations (especially by farmers). Concerning overgrazing, it was accepted and even proposed by some people interviewed that a reduction in the reindeer density is sometimes necessary, while the sheep density at the present time was of no concern. On the other hand, it was observed that in parts of Målselv the high density of sheep has reduced the lichen coverage (winter pastures for reindeer) in both forests and heaths (cf. Chap. 17).

According to statements given in the interviews, local people, the Sámi or other nationalities, need to be involved in the decision-making process about how local resources are to be exploited under current conditions (see Chap. 18), and people generally agree that some restrictions are needed today. These should be based on scientific knowledge and may vary between districts. Reindeer herders stressed that birch is crucial for herd management, and thus needs to be sustained as a local resource for both animals and people (see Chap. 23). In general, these people agreed that the current amount of wood taken from the mountain birch ecosystem was sustainable. In their view, wood harvesting could even be increased within the limits of sustainable management. However, the possible severe outbreaks of the autumnal moth by climate change in areas which were previously too cold for such attacks (see Chap. 13), and death of birch, may influence the wood harvesting by local people, e.g. wood for fuel. It has been stated that primarily old stands and trees of polycormic birch are attacked by the moth (see Chap. 12), exactly those trees commonly used for firewood. This means that the quality of the wood for this use may change and thus, socio-economically influence the use of the forests.

Reindeer husbandry is one of the methods by which humans exploit the Nordic mountain birch forest, and it is an important contributing element to the socio-economic well-being of the reindeer owners (see Chap. 19). However, conflicts between reindeer husbandry and other uses of the birch forests may occur. A management plan must take these factors into consideration in a holistic approach in order to arrive at policies whose goals are the sustainable use of the mountain birch forests without destruction of these resources. Local residents, including the Sámi as well as non-Sámi, have a common knowledge of the mountain birch and share traditions concerning the natural environment (cf. Chap. 20). The strong influence of this ecosystem in the life of the Sámi is shown by their fundamental concept of birch, 'soakhi', which includes an intricate vocabulary expressing both natural phenomena and the practiced management of wood resources.

Following the construction of new roads, there has been an increase in tourism. In many areas, tourism in the Nordic mountain birch forest is today the fastest-growing economic sector. Particularly in northern Sweden and in northern Finland, and in the mountain birch region in southern Norway, several hotels have been built, often with cottage villages near by (see Chap. 15). This has increased the number of people hiking on paths in the surroundings of the hotels, causing strong local disturbance of the vegetation by trampling (see Chap. 14). In contrast, people using more remote areas in the mountain birch forests have much less impact on the vegetation. There has been good experience both in Sweden and in Finland in restricting damages/erosion to the ground by building boardwalks etc. in the most heavily used and sensitive places (see Fig. 15.2, Chap. 15). This kind of infrastructure building helps also in "channelling" the pressure to nature into relatively small areas, leaving most of the surrounding areas undisturbed.

There are different types of tourists attracted by the northern nature. Some are interested in downhill skiing (and the number of these tourists in the north may increase if climate warming shortens the winter season in more southern areas), others are interested in motorized activities or fishing, particularly in summer, while many tourists come just to see the beauty (especially the autumn colours) of unspoiled nature in the north. This last group will avoid big hotels and cottage villages where the flora and fauna have been disturbed. It is, therefore, important that some areas in the north are preserved from too much hotel tourism. Large nature reserves, wilderness areas and national parks have already been established in Finnish and Swedish Lapland, and in northern Norway, and more are planned in the latter country. At the outskirts of these, nature trails may be recommended to particularly beautiful spots. Such trails have already been built, also in the mountain birch region, particularly in Finland (cf. Chap. 15).

While developing tourism in the northern birch forest region, potential conflicts with other forms of land use (e.g. reindeer husbandry) should be carefully considered, and minimized (cf. Chaps. 23 and 24). Large tourist centres often need parking lots and ski lifts near the hotels, which means total destruction of the birch forest ecosystem (see Fig. 24.3, Chap. 24). Fortunately, these effects are often rather limited in area, but their specific location in the landscape is critical. The increased use of off-road motor vehicles (both winter and summer) has become a problem in some areas. It can cause serious disturbance to reindeer (especially during the calving period), damage vegetation and important habitats for wildlife, increase erosion, and also disturb tourists seeking a peaceful environment. Increasing tourism and numbers of cottage owners may also influence logging of the birch forest indirectly through an increased demand for fuel. Although there is potential for conflict between tourism and reindeer herding, it should be remembered that the reindeer are an important tourist attraction, and consequently, the synergism between reindeer husbandry and tourism should be utilized.

The goals for utilization of the mountain birch ecosystem are probably among the most important factors when discussing their sustainability. In general, one would aim for the utilization or management that gives the highest welfare for man without endangering the persistence of the ecosystem. This may include local, regional, and even national income and employment, in addition to local and regional cultural values (see Chap. 16). Although tourism today is the fastest-growing economical sector in the Nordic mountain birch forest, logging for industrial purposes might be a factor for local income and employment in more productive areas at low altitudes. Such logging of an expanding birch forest (in addition to logging for fuel and increased infrastructure of the area) has been done in Målselv in northern Norway. On average over the last 10 years, however, industrial use of birch for particleboard production and use as firewood in the area together accounted for less than 30 % of the annual growth of birch (see Chap. 16). In addition, birch is used for handicraft and furniture production, on a small, although important scale. If the logging scheme is performed in a manner that facilitates overall forest penetration for grazing ungulates, additional advantages may be achieved in a broader context (see Chap. 22).

In many districts of northern Fennoscandia, sustainable mountain birch forest management allows for more logging (cf. Chap. 16). Model results from the HIBECO project (see Chaps. 21, 22) raise the question whether changes in the logging practice to a so-called scale-free logging policy, which in the long run creates a forest mosaic with many small logging plots and a few larger ones (rather than small ones only), may be a better strategy, since it increases the penetration of the forest by grazing animals (see Chap. 17), due to a higher degree of overall connection between recently logged sites (see Chap. 22).

One important feature of the forest is a relatively open structure with a mosaic of different age-structured forest patches. In Sámi districts this structure has been maintained by tree felling for firewood, and in many areas leaf-eating insects such as *Epirrita* have had an important role creating such patterns as well. Due to the expanding modern infrastructure in the districts, some of these wood felling areas are not used any more. Thus, the decaying trees are overgrown with rather dense and twisted small birches because of low light intensity (see Chap. 18). In a nutrient-poor and dry soil, it is probably easy to keep an open birch forest structure by light wood felling, or by no grazing, or light grazing pressure, even with an expected climate change. However, in nutrient-rich soil and under good moisture conditions, particularly in the more oceanic mountain areas of Norway, this is, as already mentioned, expected to be different. Here, the tendency is towards a dense young birch forest (Chap. 17; Wielgolaski, unpubl.; Leif Ryvarden, pers. comm.) with many seedlings, partly because of a reduced level of grazing by domestic animals due to less summer farming in these areas (Bryn and Daugstad 2001). With climate change, the trend of densification in rich and moist soil can be expected to increase over larger areas due to the increased tree line (Kullman

2002) and a higher amount of nitrogen produced by increased precipitation (Tømmervik et al. 2004). If the strategic goal under these conditions is to maintain a network of open and interconnected patches for the benefit of grazing and habitat heterogeneity in the future, what are the alternatives to an intensified thinning and logging practice?

In nutrient-rich and moist forests, also birch forests, deliberately ignited forest fire is one option to obtain open forest patches (e.g., Bleken et al. 2003). The opening-up of dense forest by fire has a long tradition up to relatively recent times (cf. Chap. 10) and birch is relatively susceptible to fire. Theoretically, using chemicals such as glyphosate is also a possibility to kill young birch stands and other deciduous bushes as done earlier in coniferous forests (Statistical Yearbook of Forestry 1974). It has, however, substantial side effects on the natural ecosystem, and in Sweden the use of herbicides for weeding was abolished by law in 1980 (Hytönen 1995),therefore, no spraying of herbicides has occurred since 1986. In Norway, no state subsidies have been given for, e.g., the use of herbicides since 1989.

Intense grazing, e.g. by sheep or reindeer, early in the recovery of a birch forest is another option. It may maintain open grazing fields, and even produce new fields for more optimal grazing in the long run. Strong grazing by reindeer, however, destroys the main winter forage and the lichen mats in winter forage districts (cf. Chaps. 11 and 17). Moreover, strong winter grazing by sheep will be detrimental to good management policy in areas where such grazing is possible (see Chap. 10). The result of high plant intake by domestic animals like sheep has already been mentioned as an important reason for destruction of vegetation, soil degradation and erosion, e.g. in potential birch woodland areas in Iceland (Aradottir et al. 2001).

A properly "tuned and steered" intensity of local grazing pressure from ungulates on recently logged sites (herding and fencing) may, on the other hand, contribute to controlling the actual birch tree line expansion relative to the potential, climatically determined tree line, at least in some local areas of particular importance (cf. Chaps. 21 and 22). However, today, future control of increasing Nordic mountain birch forests even in moist and nutrient-rich soil seems to be mainly of theoretical interest, but this may change through time, at least in some districts. It is worth remembering that an increased biomass of mountain birch forest in the future also represents an option (or, from a conservational perspective: a potential threat) for more industrialized utilization of birch for firewood as well as for other uses such as lumber and furniture in this region (cf. Chap. 16).

25.4 Considerations for Sustainable Reindeer Management

In many districts of fragile, nutrient-poor mountain birch woodlands, reindeer densities have been so high in winter grazing areas that lichen vegetation is severely reduced (e.g., Tømmervik et al. 2004). In order for the lichen vegetation to recover in these areas, lower reindeer densities are essential (cf. Chaps. 4, 11, 16, 17). In contrast, in an established mountain birch forest, moderate grazing may improve growth of fodder plants and keep the establishment of new birch sprouts at a moderate level. Management decisions should be based on detailed information of local conditions (soil fertility, climatic conditions, vegetation type, pasture rotation, the condition of lichens in the forests etc.). This is clearly indicated in some studies where strong site-specific effects of reindeer grazing on soil quality and nutrient turnover were found (cf. Chaps. 11 and 19; Stark 2002). It is recommended that the optimal production of the lichen pasture is when the height of the lichen (thickness) is in the range 2–5 cm (lichen coverage>50 %), which means a standing biomass of 220–700 g/m^2 (see Chap. 24; Gaare and Tømmervik 2000).

Studies from northern Fennoscandia show that the carrying capacity varies a lot, but when compared to carcass weights (slaughtering weights and production), the recommended density for winter grazing areas (restricted use only in winter) generally is higher than in "year-round districts" (cf. Chaps. 11, 16, 19, 24). In Målselv the recommended density in winter grazing areas is estimated to be only 1.5–2.0 reindeer km^{-2}, due to high numbers of sheep, cattle and goats and the military activity. This is less than one quarter of the recommended densities in the most productive reindeer districts.

Pasture rotation alone is not necessarily an efficient tool for sustainable pasture management, since both reindeer herds with and without pasture rotation can overgraze their food sources (western Finnmark; cf. Chap. 19). Therefore, pasture rotation and controlled reduction of grazing pressure should be applied simultaneously. So far, the effects of overgrazing are most striking in the winter pastures, but Eriksson et al. (1998) found that in Sweden grazing reduced the lichen coverage also in spring, summer and autumn pastures. Generally, however, the situation is better in Sweden, according to Moen and Danell (2003), than in northern Norway and Finland. They conclude that large-scale overexploitation by reindeer in the Swedish mountains and in mountain birch forests (summer grazing areas) is not evident, but strong grazing and trampling effects may be found around enclosures and fences. On the other hand, they concentrated mainly on the summer grounds since impacts on winter grounds are strongly correlated with forestry practices, making it more difficult to separate the effects of forestry from those of reindeer husbandry. In future management schemes, summer pastures, especially grass- and sedge-dominating boglands, should be preferred, since they can compensate and even overcompensate the grazing damage (cf. Chap. 11;

Wegener and Odasz 1997). In contrast, the most sensitive areas (establishing young birch stands) might need protection from intensive, active herding if we want the forest to expand.

The management perspective may be broadened by including, on the one hand, the interplay between the shifting mosaic of birch forest stands and the influence from forest management policies in this respect (see Chaps. 23 and 24) and, on the other hand, the temporally increased availability of food resources for various ungulates in recently logged areas. These interactions can to some degree be explored at least phenomenologically in model simulations (see Chaps. 21 and 22), as an important supplement to field experiments and practical experience.

25.5 Final Remarks

The consequences of any new human activities should be evaluated beforehand. For instance, new pipe and power lines, as well as development of roads and cottage villages, will reduce the availability of pasture areas in the vicinity to a great extent, and the areas further away from them will encounter higher grazing pressure than previously.

These developments, very much connected with rising numbers of people in the area either permanently or temporarily, are as follows: (1) increasing demand for the commercialization of firewood production mainly driven by interests outside the ecosystem; (2) expanding infrastructure for on- and off-road transportation by motorized vehicles as well as larger numbers of tourists and recreationists during all seasons; (3) failing management structures and strategies to cope with sustainability and biodiversity that reflect particularly the expectations and requirements of the population living permanently in the mountain birch forest ecosystem and who have a stake in the birch resource in relation to other economic opportunities. Thus, the current context asks for the negotiation of management regimes which will allow us to accommodate and meet the needs of the local population and not driven by external interests that are tied to the processes of globalization. Based on results provided by the conducted studies, it is assumed that if appropriate changes are not achieved, the future integrity of the mountain birch will be in jeopardy.

References

Aas B, Faarlund T (2001) The Holocene history of the Nordic mountain birch belt. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 5–22

Aradottir AL, Thorsteinsson I, Sigurdsson S (2001) Distribution and characteristics of birch woodlands in North Iceland. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 51–61

Bleken E, Mysterud I, Mysterud I (eds) Forest fire and environmental management: A technical report on forest fires as an ecological factor. Directorate fire electrical safety, Tönsberg and Univ Oslo, Oslo

Briffa KR, Bartolin TS, Eckstein D, Jones PD, Karlén W, Schweingruber FH, Zetterberg P (1990) A 1,400-year tree-ring record of summer temperatures in Fennoscandia. Nature 346:434–439

Bryn A, Daugstad K (2001) Summer farming in the subalpine birch forest. In: Wielgolaski FE (ed) Nordic mountain birch ecosystems. UNESCO, Paris and Parthenon, New York, pp 307–315

Crawford RMM (2000) Ecological hazards of oceanic environments. New Phytol 147:257–281

Eriksson O, Niva M, Raunistola T (1998) Långtidsförändringar av fjällväxtlighet. Några exempel från norra Lappland. In: Olsson O, Rol M, Torp E (eds) Hållbar utveckling och biologisk mangfald i fjällregionen. Forskningsrådsnämnden, Stockholm, pp 184–198

Gaare E, Tømmervik H (2000) Monitoring of lichen grazing areas in Finnmark. NINA Oppdragsmelding 638:1–33

Hanssen-Bauer I, Tveito OE, Förland, EJ (2000) Temperature scenarios for Norway: empirical downscaling from the ECHAM4/OPYC3 GSDIO integration. DNMI Rep 24:1–53

Hanssen-Bauer I, Tveito OE, Förland EJ (2001) Precipitation scenarios for Norway: empirical downscaling from the ECHAM4/OPYC3 GSDIO integration. DNMI Rep 10:1–39

Høgda KA, Karlsen SR, Solheim I (2001) Climate change impact on growing season in Fennoscandia studied by a time series of NOAA AVHRR NDVI data. Proc IGARSS 2001, Sydney, Australia, pp 1–3

Høgda KA, Karlsen SR, Solheim I, Tømmervik H,. Ramfjord H (2002) The start dates of birch pollen seasons in Fennoscandia studied by NOAA AVHRR NDVI data. Proc IGARSS, 2002, Toronto, Canada, pp 1–3

Holmgren B, Tjus M (1996) Summer air temperatures and tree line dynamics in Abisko. Ecol Bull 45:159–169

Hytönen M (ed) (1995) Multiple-use forestry in the Nordic countries. METLA, Helsinki

IPCCWG1 (2001) Intergovernmental Panel on Climate Change Working Group 1. Climate change 2001: the scientific basis. Cambridge Univ Press, Cambridge

Juntunen V, Neuvonen S, Norokorpi Y, Tasanen T (2002) Potential for timberline advance in northern Finland, as revealed by monitoring during 1983–1999. Arctic 55:348–361

Karlsson PS, Weih M (2001) Soil temperatures near the altitudinal and latitudinal distribution limit of the mountain birch (*Betula pubescens* ssp. *czerepanovii*): Implications for seedling nitrogen economy and survival. Arct Antarct Alpine Res 33:88–92

Kozlov MV, Barcan VS (2000) Environmental contamination in the central part of the Kola Peninsula: history, documentation and perception. Ambio 29:512–517

Kullman L (2002) Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. J Ecol 90:68–77

Luoto M, Seppälä M (2003) Thermokarst ponds as indicators of former distribution of palsas in Finnish Lapland. Permafrost Periglacial Proc 14:19–27

Moen J, Danell Ø (2003) Reindeer in the Swedish Mountains: an assessment of grazing impacts. Ambio 32:397–402

Mysterud I (2003) Anthropogenic burning and impact. In: Bleken E, Mysterud I, Mysterud I (eds) Forest fire and environmental management: a technical report on forest fires as an ecological factor. Directorate fire electrical safety, Tönsberg and Univ Oslo, Oslo, pp 49–79

Räisänen J, Hansson U, Ullerstig A, Döscher R, Graham LP, Jones C, Meier M, Samuelsson P, Willén U (2003) GCM driven simulations of recent and future climate with the Rossby Centre coupled atmosphere – Baltic Sea regional climate model RCAO. Swedish Meteorological and Hydrological Institute, Rep no 101, 61 pp

Stark S (2002) Reindeer grazing and soil nutrient cycling in boreal and tundra ecosystems. Acta Univ Ouluensis, Ser A 382

Statistical yearbook of forestry 1974 (1976) Official statistics of Sweden. National board of forestry, Jönköping, p 43

Tømmervik H, Høgda KA, Solheim I (2003) Monitoring vegetation changes in Pasvik (Norway) and Pechenga in Kola Peninsula (Russia) using multi-temporal Landsat MSS/TM data. Remote Sensing Environ 85:370–388

Tømmervik H, Johansen B, Tombre I, Thannheiser D, Högda KA, Gaare E, Wielgolaski FE (2004) Vegetation changes in the Nordic mountain birch forest: the influence of grazing and climate change. Arct Antarct Alpine Res 36:322–331

Wegener C, Odasz AM (1997) Effects of laboratory simulated grazing on biomass of the perennial Arctic grass *Dupontia fisheri* from Svalbard: evidence of overcompensation. Oikos 79:496–502

Whitfield J (2003) Too hot to handle. Nature 425: 338–339

Wielgolaski FE (2001) Field- and bottom-layer vegetation mat transplantation: a method to simulate possible effects of climate change? Skograektarritid 1:167–170

Subject Index

A

Abisko 8, 9, 32, 100, 102–104, 106, 107, 110, 113, 127, 131–134, 166–168, 206, 226, 228, 335
adaptation 13, 14, 88
aerial
- photographs 62
- satellite remote sensing 57
agricultural expansion 256, 275
agricultural land 333, 344
Alces alces 14, 75, 141, 184, 186
Alectoria spp. 211
allometric relationship 56
Alta 19, 20, 24, 25, 32
andosoil 13
annual shoot length 93
annual tree rings 77, 78, 81
anthropogenic activity / change/ effect / impact 6, 36, 48, 51, 166, 184, 197, 236, 248, 251, 277, 283, 290, 298, 347
apical dominance 13, 175
arctic circle 5
Argyresthia retinella (birch bud moth) 135, 173, 175
artists 262, 263
autumn
- colours 4, 350
- phenology 106–108
- senescens 106
autumnal moth 38, 50, 62, 75, 77–79, 82, 102, 120, 125–127, 129–133, 135, 165–177, 184, 185, 225, 287, 292–294, 298, 343, 347

B

basal sprouts 165, 167
bedrock 13, 20
Betula
- *glandulosa* 4, 117
- *nana* 4, 12, 74, 94, 106, 117, 128, 157, 162, 163, 166, 197, 198
- *pendula* 4, 89, 109
- *pubescens* 4, 12
- *tortuosa* 4
bilberry (blueberry) 14, 346
biodiversity 214, 276, 280, 302, 313, 316, 324, 333, 338, 344, 348, 354
bioenergy 230, 280
biomass 11, 24, 55–67, 79, 80, 129, 157, 160, 161, 223, 225, 226, 249, 294, 303, 352
biotopes 279
birch
- bud moth, see *Argyresthia retinella*
- taxonomy and genetics 4, 74, 75, 117
- utilization 225, 229, 255–257, 259, 261, 263, 267, 275–280, 295, 303, 313–315, 317–319, 322–325, 347, 348, 351, 352
bleaching layer 13
blueberry (bilberry) 14
branching 142, 146
brown soil 28
browsing 5, 7, 12, 135, 139–147, 149, 150, 186, 187, 328, 347
bryophytes 11
Bryoria spp. 211
bud break / burst 6, 77, 94, 95, 99, 101, 103–107, 113, 131, 168
building material 329, 330

C

calcareous ground 11
Caledonian mountain chain / Caledonides 6, 13
Cambro–Silurian 13
camping 193, 194, 203–205, 207, 209, 242, 279, 313, 329, 332, 334, 335, 353
Capreolus capreolus (roe deer) 141, 152, 184, 186
carbohydrates 12, 90, 91
Carex bigelowii 197
carrying capacity 213, 214
cation exchange ratio (CEC) 28, 30, 32
cattle browsing 171
Cervus elaphus (red deer) 141, 152, 184, 186
Cetraria spp. 199, 239, 240
changing climate 345, 346
charcoal 13
Cladonia spp. 199, 237, 239–242, 245–248
clear-cutting 304, 305
climate 7–11
– change 5–7, 47, 51, 87, 106, 113, 130, 134, 158, 166, 174, 176, 177, 185, 235, 240–242, 247–249, 277, 290, 293–295, 301, 303, 310, 324, 345–347, 349–351
climatic variation 143, 158
clipping 142–146, 183
coastal region 6
cold air "lake" 167, 176
colluvisol 23, 24, 27, 28
– communities 22
colonization 193, 197
co-management regimes 322
common property 259, 317
compensatory growth 140, 144, 145, 187
competition 301
complexity 283, 284, 286, 288, 289, 306
computer simulations 289, 307
conceptual models 298
coniferous forest / species / trees 3, 6, 7
continental 6, 10, 11, 99–103, 106–108, 111, 112, 126, 127, 131–133, 135, 166, 183–187, 293, 294
core-periphery relationship 338
Corno-Betuletum 41, 43, 46, 47
Cornus suecica 11, 42, 46, 47, 49, 51, 238, 240–242, 247–249, 277, 278, 346
Cornus-Myrtillus birch forest(s) 241, 242, 244–246, 248, 249
correspondence analysis 236, 237, 241
Corylus avellana 11
costs 227, 266, 280
cottage villages 329, 334, 350, 354
crowberry 346

D

dams 332
deciduous dwarf shrubs 196, 208, 212
decision-makers / making 313, 323, 325, 348, 349
defoliation 125,127–129, 134, 135, 161, 165, 167, 171, 175–177, 225, 292, 294
degradation 6, 13, 196, 279, 338, 344, 349, 352
dehardening 95
demography, intracell 290
dendrochronology 36, 37, 49
Deschampsia flexuosa 14
desert soil 13
desertification 328
Devonian 13
diameter growth 111
Dicranum spp. 195, 238, 240, 241
disease 130, 150, 260
disturbance 6, 125, 157, 177, 187, 193, 195–199, 209, 210, 212–214, 228
Dividalen 128, 172
domestic animals / herbivores 5, 13, 275
dormancy 94
dormant buds 72, 113, 120, 167
– effects on stand dynamics 120
dormant clip 144, 145
downhill skiing 206, 207, 210, 213, 337, 350
drought stress 6
Dryas octopetala 198
dwarf cornel 346
dwarf shrubs 160, 161, 163

E

ecological interactions 290
economic feasibility 264, 279, 280, 314, 319
economy 348, 350
ecosystem management 315, 316
ecotone 328
ecotourism 279

ecotype 4
ecotypic differentiation 101–113
– effects on survival 102
egg-killing air temperatures 167, 176
elevated CO_2 93
emergent properties 287, 288, 308
Empetro-Betuletum 237, 240
Empetro-Betuletum pubescentis 23, 41, 43–44, 49–50
Empetrum hermaphroditum 11, 14, 346
Empetrum-lichen-type 328
Empetrum nigrum 197, 277
environmental impacts 330, 336
Epirrita 351
Epirrita autumnata 38, 50, 62, 75, 77–79, 82, 102, 120, 125–127, 129–133, 135, 165–177, 184, 185, 225, 287, 292, 294, 343, 347
Eriocrania moths 173
Eriophorum angustifolium 198
erosion 13, 147, 152, 186, 194, 195, 197, 207, 208, 210, 212, 332, 344, 350, 352
ethnic tensions 256
European Union (EU) 271, 276
eutrophic 12, 310
evaporation 25
evapo-transpiration 56
evergreen 196, 208
event year 36
everyone's rights 203

F

Fagus silvatica 11
Faroe Islands 6
feedback 125, 129, 302
felling 173, 220, 229, 230, 258–263, 267, 279, 317–321, 323, 330, 332, 333, 351
ferns 11
Finnmark 158–160, 163–164
Finnmarksvidda 132, 169, 173, 175, 293, 301, 330
fire 310, 352
firewood 223, 224, 235, 252, 258–267, 279, 280, 285, 286, 289, 303, 314, 315, 317, 319–323, 328–332, 349, 351, 352, 354
fishing 212, 350
fodder plants 353
foliage quality 129, 130, 135
food resources 354
foot trails, see trails
forest
– age 165, 170
– communities 41, 42, 44, 46, 49–51, 240, 247, 249
– cycling 176
– densification 301, 303, 310
– exploitation 309
– fire 310, 352
– industry 225, 303, 304, 318, 320, 321, 348, 351
– limit 131, 173, 176
– line 19–21, 24, 25, 31
– management 283, 292, 293, 296–298, 303, 309
– tundra 328
– type 26, 28, 31, 41, 45, 49–51, 161, 170, 174, 176, 224, 260, 328
– units 41
forestry 161, 203, 204, 209–211, 221, 227, 230, 231, 256, 265, 267, 270, 279, 280
four-wheeled cars 205, 212, 223, 224, 332, 344
fractal pattern 298, 306, 307, 309
frost hardiness 94, 95
frost resistance 94
fuelwood 13, 222, 225, 228–231, 279, 280, 351

G

gelifluction 25
genetic incompatibility 4
genotype–environment interactions 74, 75, 89–91, 117, 118
geographical information system (GIS) 57, 131, 291
geology 13, 20
geomorphology 22
Geranio-Betuletum 41, 43, 47–49, 51
germination 151
GIMMS NDVI data 57, 61, 62
gley 23, 27, 28, 30–32
global change, see climate change
globalization 255, 259, 280, 335, 354
glyphosate 352
gneiss 13
graminoid(s) 140, 196, 208, 209, 212
granite 13
grass 157, 160, 161, 163, 186, 348

grazing 5, 6, 13, 14, 135, 139–142, 146–152, 157, 158, 160–163, 183, 184, 186–188, 223, 290, 293, 295–299, 301, 309–311, 327–329, 347, 351–353
Greenland 4, 102, 140, 141, 146–150, 152, 153, 184, 186, 187, 289
greenness 57
grid cell 285, 290, 296, 305, 308
grouse 102, 185, 186
growth 26, 31, 71–82, 100, 110–112, 119, 120, 143–146, 149, 346
– diameter 111
– effects of CO_2 93
– effects of herbivory on 75, 77–79
– old 297, 298, 304, 306–310
– rate 296, 298, 305
– summer temperature 96
– winter temperature 93

H

habitat facilitation 299
Hafnarskogur 100, 102, 103, 106, 107, 111
handicraft 224, 225, 230, 262–264, 280, 303, 314, 323, 328, 338, 349, 351
hare (*Lepus timidus* & spp.) 75, 102, 149, 184, 186, 188
harvesting 221, 229–231, 235, 295, 298, 302–304, 310
hayfield 13
heat sum 7
heath vegetation 165–168, 196–199, 204, 205
heavy metals 163
herbicide 352
herbivores
– damage by 102
– effects on tree growth 73, 75, 77–79, 120, 126, 139, 140, 142–146, 162
hiking 193, 195–199, 203–205, 207–213, 279
– paths 205, 207, 208, 331, 333, 334, 350
holistic approach 337
hotels 206, 210, 329, 331, 332, 334, 336, 337, 350
human exploitation / impact / interaction 206, 212, 284, 276, 277, 289, 290, 332, 344
humidity 6, 11, 346
– section 10
hybridisation 4, 12, 74, 106, 117, 166
hydroelectric power 332, 333, 337
Hylecoetus dermestoides 79, 174, 175

Hylocomium splendens 14, 195, 238, 240–242, 248

I

ice crust / layer 158, 240, 248, 249, 346
Iceland 4, 6, 13, 101, 140–145, 147, 150–153, 184, 186, 188, 196, 289, 344, 347, 352
Icelandic birch provenances 94
Inari 128
income 184, 203, 209, 211, 220, 222, 227–229, 230, 270, 272, 280
inducible changes 129, 130
industrial forestry 225, 256, 265, 280, 303, 304, 318, 320, 321, 348, 351
infrastructure 318, 330, 331, 333, 337, 344
insect 7
– attacks 288, 289
interactions, spatio-temporal 285, 288–290
introgression / introgressive hybridisation, see hybridisation
inversion 131, 292, 294
invertebrates 12
IRS 1D 59
isotherm 294

K

Kautokeino 8, 9, 24
Kevo 8, 9, 100–113, 131, 132
Kilpisjärvi 8, 9, 15, 100–104, 107, 109, 113
Kola Peninsula 4, 344

L

Lagopus lagopus 102
Lake Torne 131, 133, 166, 168–171, 204, 206, 213, 335, 336

land use 134, 140, 203–205, 207, 209–211, 213, 227, 250, 270, 272
- practices 257, 259, 267

Landsat 59, 128
landscape heterogeneity 291, 302
large-scale reindeer herding 269–271
leaf
- area 145
- index (LAI) 56, 57, 64, 80
- ratio (LAR) 92
- autumn senescence 106
- respiration 92

leaf-eating insect 287, 292, 298, 351
legal system 318
Lepus timidus, see hare
lichen 11, 157, 158, 160–163, 170, 186, 187, 199, 208, 211, 212, 223, 226, 235, 238, 240–242, 247, 249, 277, 328, 329, 346, 347, 349, 352, 353
- cover 328, 329
- pasture 329

lime 13
livelihood 125, 185, 203, 205, 212, 222, 255–257, 264, 267, 314
livestock 14
logging 6, 288, 292–298, 302–308, 310, 311, 333, 347, 350, 351, 354
long shoots 144, 146
lumber 352

M

Målselv 127, 235–237, 246, 247, 249, 329, 338, 349, 351, 353
management 126, 129, 139–141, 143, 146, 147, 149, 151–153, 158, 161, 163, 187, 188, 206, 214, 220, 226, 230, 232, 247, 250, 255, 258, 261, 264–267, 272, 276, 279, 280, 313, 315, 316, 318–320, 322–325, 328
- regimes / policies 283, 289, 291–293, 296, 298, 299, 301, 302, 305, 309–311, 352, 354

maritime 13
market demand 323
Máze 21, 22, 24, 26–31, 36–38, 40, 47, 48, 127, 131–135, 235–238, 242, 244, 248–250, 347
meadow vegetation 165, 168, 169, 196, 197, 245, 246
Melanelia olivacea 42, 44, 46–49, 242
Melbu 8, 9, 15
meristem
- dynamics 72
- RGR 144, 145

metamorphic 13
micashists 13
migration 224, 228, 256, 270, 272
military activity 246, 247, 338, 348
mineral resources 301
minerals 12, 14
mining 210, 329, 330, 333, 347
mobility (human) 279
model scenarios, simulations 289–298, 302, 305–311, 354
monitoring 126–128, 141, 167, 183, 194, 207, 244, 246
monocormy 4, 11–13, 75, 79, 108, 109, 165, 168–177, 183, 185, 236, 241, 242
moon cycle 260, 261, 263
moose (*Alces alces*) 14, 75, 141, 184, 186
mortality rate 293
mosaic pattern 175, 288, 291, 293, 297, 301, 303, 305, 307, 308, 310, 311
mosses 195, 235, 237, 240, 241, 248, 249, 277
motor bikes 205, 209, 212, 213, 332, 344, 354
motorized traffic 214, 228, 264, 272, 279, 327, 348
multiple use 219, 317, 318, 321, 322
mycorrhiza 14

N

nanopodzol 23–29, 31
national parks 14, 203–207, 209–212, 334, 335, 350
nature conservation 203, 204, 209–212, 315, 335
NDVI 58, 67
near-infrared 57
nemoral 11
net production 56, 163
nitrogen (N) 14, 15, 176, 223, 247, 249, 250, 346, 352
- productivity 73
- uptake 72, 74

NOAA AVHRR 59
non-linearity 288, 289
normalized difference vegetation index (NDVI) 58

Norrbotten 159, 160
North Atlantic Oscillation (NAO) 158
northern boreal 3, 11, 205
Norway coast 126, 131–135
nutrient 40, 41, 43–48, 50, 351, 352
– availability / conditions 12–14, 346, 351–353
– uptake 72, 74, 81, 196
– soil 31, 32, 169, 185, 193, 197, 198, 223

O

oceanic 6, 10, 11
Ochrolechia frigida 199
off-road traffic 205, 332, 344, 345, 350
oligotrophic 11, 12
open top chambers 93
Operophtera brumata (winter moth) 125–127, 130, 135, 165, 168–174, 176, 177, 184, 292
organic carbon content 28, 29
outbreak 125–131, 161, 165–177, 183–185, 343, 344, 347, 349
outdoor activities 203–205, 331
out-farming 347
overexploitation 333, 335, 337
overgrazing 157, 295, 296, 328, 338, 344, 346, 349, 353
oxygen 346

P

Paistunturi 158, 159
Paliskunta 270
Pallas-Ounastunturi 205–212
Pallasjärvi 100–104, 106, 107, 109–111, 113
palsa bog 21, 23, 27, 346
parasitoids 129, 130
parking lots 209, 210, 336, 337
particleboard production 225, 228–230, 351
pasture 158, 160, 186, 249, 270, 271, 327, 338, 349, 352–354
– rotation 158, 162, 163, 187, 226, 270–272, 328, 329
paternia 23, 28
path, see hiking path
periodic 126,127, 135
permafrost 21, 24, 26, 27
perturbations 288, 293–298
pH, soil 25, 28–30
phenology 6, 72, 77, 99–113, 119, 120, 130, 131, 346
– autumn 106–108
phenophases 14, 15
phenotypic plasticity 113
phosphorus (P) 15
photosynthesis 91
phyllites 13
pine 11
pixel 57, 285, 290
plant communities, see forest communities
Pleurozium schreberi 14, 195, 238, 240, 242, 248
podzol regosol 22–29, 31
pointer year 37–40, 50
policies 313, 322, 323, 325, 349
policy recommendations 266, 279, 280
pollution 344
polycormy 4, 12, 79, 108, 165, 166, 168–171, 174–176, 183, 185, 236, 349
polytopic history 4
Polytrichum spp 195, 199, 238, 242
potassium (K) 14, 15
power lines 329, 354
Precambrian 13
precipitation 7, 10, 11, 24, 26, 39, 40, 49–51, 106, 130, 132, 134, 158, 161, 166, 176, 227, 236, 240, 247–249, 293, 346, 352
– normal 9
predators 129, 130, 186, 271
predictor 296
productivity 79, 80, 99, 135, 157, 158, 161, 186, 193, 197, 222, 225, 227, 231, 272, 343, 346
public authorities 314, 324, 325
public lands 317
pulp and paper industry 317

Q

quality of life 275, 276, 280
Quaternary deposites 20

R

Radiocarbon dating 3
railroad 329, 330, 337

rambla 23, 28
ranker 23
raw humus 13
recover/y 125–127, 135, 146, 147, 152, 175, 183, 185, 187, 188, 193–195, 198, 204, 207, 225, 226, 249, 352, 353
– time 167, 168
recreation 193, 194, 199, 203–214, 228, 267, 314, 332, 335, 338, 348, 354
red deer, see *Cervis elaphus*
reforestation 303
regeneration 135, 139, 140, 147, 151–153, 183, 185, 187, 279
reindeer 12, 289, 290, 293, 303, 309, 318, 324, 328, 332, 336, 338, 349, 352, 353
– browsing/grazing 43, 50, 51, 126, 135, 152, 157, 160–163, 166, 169, 172, 173, 176, 183, 186–188, 221, 226, 235, 248, 269, 279, 352
– census 159
– density 157, 159–163, 353
– herding 125, 157, 158, 161, 185, 187, 203, 211, 212, 255–257, 259, 269–272, 275, 301, 311, 318, 327
– husbandry 184, 222, 226–228, 231, 232, 270
– lichens 346
– management 226, 250, 272, 353
– rejuvenation 13
remote sensing 57, 66, 125, 128, 129
reserves 14, 335, 336, 350
resilience 187, 196, 198
resistance 196, 198, 212
resource management 315, 316, 322, 324, 325
respiratory losses 6
ring width 77, 78, 81
roads 129, 194, 206, 209, 222, 224, 228, 229, 231, 235, 247, 250, 252, 265, 318, 327, 329, 331, 333, 336, 337, 344, 350, 354
roe deer, see *Capreolus capreolus*
root rot 170, 175
roots 10, 90
rotation periods 305
roundup 271
Rubo chamaemorei-Betuletum 41, 43, 48

S

Sámi 157, 162, 223, 224, 227, 228, 250, 255–267, 269–272, 278, 310, 313–319, 322, 323, 325, 327, 328, 333, 349, 351
– knowledge 255, 256, 259, 264, 278, 279
saplings 12, 71, 75, 76, 99, 101, 141–147, 161, 176
– growth 75, 76, 143, 146
– height 142
scale – free and specific 285–289, 297, 298, 302–309, 311, 351
Scandes 7
scenarios, see also Model scenarios 283, 296, 301, 304, 313, 325
Scotland 4, 140–147, 151–153, 184, 186, 188, 289
seed production 177, 196
seed propagation 10
seedling 71–75, 81, 106, 110–113, 135, 151, 152, 160–162, 165, 169, 171, 173, 175, 177, 196
– biomass 89
– establishment 72, 73, 175, 177, 346
– survival 102
– performance and winter conditions 74
senescence 56, 101, 104, 106–108
sensitive areas 329, 348
settlement 48, 224, 235, 250, 258
sexual reproduction 196, 197
sheep 12, 13, 275, 277, 289, 290, 293, 303, 309, 311, 328, 338, 349, 352, 353
– browsing/grazing 140–142, 147–152, 172, 173, 186–188, 344, 347, 352
shelte 140, 151
shifting mosaic 302–307, 310
shoot elongation 93
shoot/root ratio 92
siida 257, 267, 270
Silurian 13
simulation studies 291, 295, 307, 308
skeleton plot method 36
skiing 195, 203–209, 211, 213, 222, 333, 350
ski lifts 206, 209, 210, 330, 334, 336, 350
small mammals 169, 173
snow 128, 158, 176, 346
– cover 11, 21, 41, 44–46, 48, 49, 74, 169, 240, 242, 248, 261, 293
– melt 10, 208

snowmobil(ing) 195, 212, 213, 223, 224, 264, 267, 279
socio-economy / influence / utilization 213, 285, 317, 324, 325, 343, 349
soil 19–32
– calcium 29, 30
– classification 21–23
– cation exchange capacity 28, 30, 32
– C/N ratio 13, 29
– degradation 196, 279
– distribution 23–28, 31
– moisture 10, 13, 346, 351, 352
– nitrogen 223, 352
– nutrient content 12–14, 28, 29, 31, 32, 40, 41, 43–48, 169, 185, 193, 197, 198, 223, 351, 352
– particle size distribution 28, 30
– pH 13, 25, 28–30
– phosphorus 31
– potassium 14, 31
– temperature
– – soil decomposition 88
– – growth performance 73, 74, 81
– – nutrient uptake 72, 74, 81, 96
– – seedling survival 73, 81
spatio-temporal population dynamics 286, 301, 303, 304, 310
specific leaf area (SLA) 92
spiritual places 262, 263
spring frost 95
spring phenology 103–106
sprouts, sprouting 75, 76, 165–171, 174–177, 237, 241, 353
spruce 11, 333, 338, 344, 349
stakeholders 213, 316
stand
– age 127, 168, 175
– biomass 79
standing volume 318, 320
starch 15
stem
– age structure 168, 174, 175
– diameter 142
stochastic growth 296
storage 72, 96
Strömstad treaty 269
subalpine 3, 4, 193, 203, 205, 206, 292, 298, 301, 310, 311
suboceanic 10, 11
subsidy 272
succession dynamics 302
sugar, soluble 15
summer pasture 227, 270, 271
superposition principle 285, 287, 288
sustainable development / management / use 139, 140, 184, 187, 188, 213, 255, 257, 276, 280, 296, 309, 313–316, 319, 321, 325, 328, 335, 337, 338, 343, 347–349, 351, 353, 354
syrosem 23–25, 27, 28, 31

T

taxation system 269
technological innovation 318
temperature 7, 8, 11, 14, 15, 93–95, 130–135, 146, 158, 167, 169, 175–177, 185, 290, 292–295, 346, 347
– soil decomposition 88
– frost hardiness 95
– growth 71, 73, 74, 77, 81, 92
– inversion 131, 292, 294
– normal 8
– nutrient uptake 72, 74, 81, 96
– photosynthesis 91
– seedling survival 73, 81
terrain vehicles 332, 337
tetratherm 7
thinning 292, 310
thresholds 142
tillers 198
timberline 203–205, 208, 211, 223, 247, 249, 255–258, 264, 265, 275
topograph/y, -ic, -ical 126, 127, 129–134, 185
Torneträsk (Lake Torne) 131, 133, 166, 168–171, 204, 206, 213, 335, 336
tourism 184, 193, 203–206, 209–213, 221, 222, 231, 232, 272, 279, 314, 321, 333, 336, 348, 350, 351, 354
tourist resort 331
tracks 208, 332
trade-off 147
trail 139, 150, 194, 195, 199, 205–213, 262, 318, 350
trampling 139, 150, 194–199, 204, 207–209, 212, 223, 262, 266, 289, 328, 350, 353
transpiration rate 10

transplant gardens 101–113
tree
- age 36–38, 45, 49
- line 3–7, 13, 193–197, 203–205, 207–211, 213, 223, 294, 301, 303, 310, 323, 324, 346, 347, 351, 352
- morphology 45
- rings 77, 78, 81

Troms 163, 294
tundra 125, 173, 184, 194, 196, 198, 199, 244, 255, 258, 265, 270

U

ultraviolet radiation 81
understorey (plants, vegetation) 195–197, 199
ungulate 289, 293, 295, 298, 301, 309, 310, 347, 351, 352, 354
upper oroboreal 3
utilization 219–223, 225, 227–229, 231, 255–257, 259, 261, 263, 265–267, 279, 280
- of birch, see birch utilization

V

vaccination 272
Vaccinio myrtilli-Betuletum 24, 41, 43, 46, 47, 240, 241
Vaccinio vitis-idaeae-Betuletum 41, 43, 45
Vaccinium myrtillus 11, 14, 197, 198, 237, 238, 240, 242, 245, 248, 346
Vaccinium vitis-idaea 11, 197, 238, 239
value added 228–230
vega 23, 28
vegetation
- changes 158, 204, 235, 237, 247
- communities 245, 246
- composition 332, 346
- history 3
- index (NDVI) 58
- management 247
- pattern 35, 36
- relevés 35, 40, 49, 235, 238, 242
- surveys, see relevés
- types 41, 128, 129, 147, 163
- units 35

vertebrates 12
vole 184, 186, 188
Vuotso 100, 127, 131–135

W

walking path, see hiking path
wet gley 27
wilderness 211, 348, 350
- huts 205, 207, 209

wildlife 344, 350
willow 14, 333, 344
willow grouse 102
winter
- browsing/grazing 145, 146, 149–152, 163, 352, 353
- dormancy 94
- moth 292
- pastures 158, 160, 186, 249, 270, 271, 327, 338, 349, 352, 353
- temperatures 93–95, 130–135, 146, 158, 167, 169, 175–177, 185, 347

wood
- consumption 315, 319–329
- energy 313–316, 321
- morphology 38
- quality 261

woodlots 319–322
World Heritage 335

Z

zoogenic impact 278

Ecological Studies
Volumes published since 2000

Volume 140
Rainforest Ecosystems of East Kalimantan: El Niño, Drought, Fire and Human Impacts (2000)
E. Guhardja et al. (Eds.)

Volume 141
Activity Patterns in Small Mammals: An Ecological Approach (2000)
S. Halle and N.C. Stenseth (Eds.)

Volume 142
Carbon and Nitrogen Cycling in European Forest Ecosystems (2000)
E.-D. Schulze (Ed.)

Volume 143
Global Climate Change and Human Impacts on Forest Ecosystems: Postglacial Development, Present Situation and Future Trends in Central Europe (2001)
J. Puhe and B. Ulrich

Volume 144
Coastal Marine Ecosystems of Latin America (2001)
U. Seeliger and B. Kjerfve (Eds.)

Volume 145
Ecology and Evolution of the Freshwater Mussels Unionoida (2001)
G. Bauer and K. Wächtler (Eds.)

Volume 146
Inselbergs: Biotic Diversity of Isolated Rock Outcrops in Tropical and Temperate Regions (2000)
S. Porembski and W. Barthlott (Eds.)

Volume 147
Ecosystem Approaches to Landscape Management in Central Europe (2001)
J.D. Tenhunen, R. Lenz, and R. Hantschel (Eds.)

Volume 148
A Systems Analysis of the Baltic Sea (2001)
F.V. Wulff, L.A. Rahm, and P. Larsson (Eds.)

Volume 149
Banded Vegetation Patterning in Arid and Semiarid Environments (2001)
D. Tongway and J. Seghieri (Eds.)

Volume 150
Biological Soil Crusts: Structure, Function, and Management (2001, 2003)
J. Belnap and O.L. Lange (Eds.)

Volume 151
Ecological Comparisons of Sedimentary Shores (2001)
K. Reise (Ed.)

Volume 152
Global Biodiversity in a Changing Environment: Scenarios for the 21st Century (2001)
F.S. Chapin, O. Sala, and E. Huber-Sannwald (Eds.)

Volume 153
UV Radiation and Arctic Ecosystems (2002)
D.O. Hessen (Ed.)

Volume 154
Geoecology of Antarctic Ice-Free Coastal Landscapes (2002)
L. Beyer and M. Bölter (Eds.)

Volume 155
Conserving Biological Diversity in East African Forests: A Study of the Eastern Arc Mountains (2002)
W.D. Newmark

Volume 156
Urban Air Pollution and Forests: Resources at Risk in the Mexico City Air Basin (2002)
M.E. Fenn, L. I. de Bauer, and T. Hernández-Tejeda (Eds.)

Volume 157
Mycorrhizal Ecology (2002, 2003)
M.G.A. van der Heijden and I.R. Sanders (Eds.)

Volume 158
Diversity and Interaction in a Temperate Forest Community: Ogawa Forest Reserve of Japan (2002)
T. Nakashizuka and Y. Matsumoto (Eds.)

Volume 159
Big-Leaf Mahogany: Genetic Resources, Ecology and Management (2003)
A. E. Lugo, J. C. Figueroa Colón, and M. Alayón (Eds.)

Volume 160
Fire and Climatic Change in Temperate Ecosystems of the Western Americas (2003)
T. T. Veblen et al. (Eds.)

Volume 161
Competition and Coexistence (2002)
U. Sommer and B. Worm (Eds.)

Volume 162
How Landscapes Change: Human Disturbance and Ecosystem Fragmentation in the Americas (2003)
G.A. Bradshaw and P.A. Marquet (Eds.)

Volume 163
Fluxes of Carbon, Water and Energy of European Forests (2003)
R. Valentini (Ed.)

Volume 164
Herbivory of Leaf-Cutting Ants: A Case Study on *Atta colombica* in the Tropical Rainforest of Panama (2003)
R. Wirth, H. Herz, R.J. Ryel, W. Beyschlag, B. Hölldobler

Volume 165
Population Viability in Plants: Conservation, Management, and Modeling of Rare Plants (2003)
C.A Brigham, M.W. Schwartz (Eds.)

Volume 166
North American Temperate Deciduous Forest Responses to Changing Precipitation Regimes (2003)
P. Hanson and S.D. Wullschleger (Eds.)

Volume 167
Alpine Biodiversity in Europe (2003)
L. Nagy, G. Grabherr, Ch. Körner, D. Thompson (Eds.)

Volume 168
Root Ecology (2003)
H. de Kroon and E.J.W. Visser (Eds.)

Volume 169
Fire in Tropical Savannas: The Kapalga Experiment (2003)
A.N. Andersen, G.D. Cook, and R.J. Williams (Eds.)

Volume 170
Molecular Ecotoxicology of Plants (2004)
H. Sandermann (Ed.)

Volume 171
Coastal Dunes: Ecology and Conservation (2004)
M.L. Martínez and N. Psuty (Eds.)

Volume 172
Biogeochemistry of Forested Catchments in a Changing Environment: A German Case Study (2004)
E. Matzner (Ed.)

Volume 173
Insects and Ecosystem Function (2004)
W. W. Weisser and E. Siemann (Eds.)

Volume 174
Pollination Ecology and the Rain Forest: Sarawak Studies (2005)
D. Roubik, S. Sakai, and A.A. Hamid (Eds.)

Volume 175
Antarctic Ecosystems: Environmental Contamination, Climate Change, and Human Impact (2005)
R. Bargagli

Volume 176
Forest Diversity and Function: Temperate and Boreal Systems (2005)
M. Scherer-Lorenzen, Ch. Körner, and E.-D. Schulze (Eds.)

Volume 177
A History of Atmospheric CO_2 and its Effects on Plants, Animals, and Ecosystems (2005)
J.R. Ehleringer, T.E. Cerling, and M.D. Dearing (Eds.)

Volume 178
Photosynthetic Adaptation: Chloroplat to Landscape (2005)
W.K. Smith, T.C. Vogelmann, and C. Chritchley (Eds.)

Volume 179
Lamto: Structure, Functioning, and Dynamics of a Savann Ecosystem (2005)
L. Abbadie et al. (Eds.)

Volume 180
Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests (2005)
F.E. Wielgolaski (Ed.) and P.S. Karlsson, S. Neuvonen, D. Thannheiser (Ed. Board)

Conditions of use and terms of warranty for the enclosed CD-ROM

§ 1 Concluding the contract

Opening the sealed cover of the CD-ROM binds the end user to the conditions of use and the terms of warranty. If the end user does not wish to be bound by these conditions, he should return the book including the unopened CD-ROM cover to his supplier or to Springer-Verlag and the selling price will be refunded. For the return of goods, § 7 is valid.

§ 2 Copyright and conditions of use

1. All rights pertaining to the data are owned by the author. The information is protected by copyright.
2. Springer-Verlag grants the end user, subject to legal liability, the non-exclusive right to use the data as described by the terms of this contract. Under this contract use of the data is restricted to the instructions described.
3. The data may, at any one time, only be used on one computer at a single workplace.
4. The data may be copied only once for backup purposes.

§ 3 Transfer of the data

1. Any transfer (e.g. sale) of the data to a third party and with it the transfer of the right and the possibility of its use may only occur with the written permission of Springer-Verlag or the author.
2. Springer-Verlag will give this permission when the end user up to this point makes a written application and the subsequent end user makes a declaration that he will remain bound by the terms of this contract. Receipt of permission terminates the right of the first end user and the transfer to the second end user may take place.

§ 4 Unauthorized use

1. The complete dataset is protected by
   - the laws of copyright
   - the laws governing the use of trademarks
   - the laws of trade and commerce
   - this contract.

   Violations may lead to action being taken under civil and criminal law.
2. The buyer is liable to Springer-Verlag for any damages or detriment accruing from any infringement of these regulations.

§ 5 Functional limitations

1. Even with the latest state of technological development and with meticulous care being taken during production, errors in the data files cannot be excluded.

§ 6 Warranty

1. In response to justified claims, Springer-Verlag has, as first possibility, the option of supplying the user with another copy of the data. If the claim is still not remedied, the end user can demand the return of the selling price from his supplier when he returns the CD-ROM together with the book in compliance with the terms set out in § 7.
2. A prerequisite to making a claim under the warranty is that the end user supplies an exact description of the defect in writing.
3. The end user has no claim to a reduction in the selling price or to correction of defects. In other respects the German Code of Civil Law (BGB) concerning the warranty of goods shall apply (§§ 459 to 480 BGB).

§ 7 Returning the databank

1. The customer can only return the CD-ROM together with the book (e.g. according to § 1 or § 6 Sect. 1.) in its entirety together with the original sales receipt/invoice. In addition he has to hand over the declaration stating that no copies remain in his possession.

§ 8 Help

1. Questions should be mailed or sent via mailbox to Springer-Verlag. The answers from the author are merely forwarded by Springer-Verlag without being checked. The questions are normally answered in the order they are received. It will not be possible to answer every question.

§ 9 Liability

1. Springer-Verlag and the author are only liable for willful intent, gross negligence, and when the data fail to fulfill their assured purpose and function. The assured purpose and functions are those which are explicitly declared in writing.There is no liability for information described in § 8.
2. The liability under German law for product liability is unaffected.
3. The plea that the end user is also at fault remains an option for Springer-Verlag.

§ 10 Conclusion

1. The location of the competent court for all legal action in connection with the databank and this contract is 69115 Heidelberg, Germany, if the contract partner is a registered trader or equivalent, or if he has no legal domicile in Germany.
2. This contract is exclusively governed by the laws of the Federal Republic of Germany with the exception of the UNCITRAL laws of trade and commerce.
3. Should any provision of the contract prove unenforceable or if the contract is incomplete, the remaining provisions will remain unaffected. The invalid provision shall be deemed replaced by the provision which in a legally binding manner comes nearest in its meaning and purpose to the unenforceable provision. This shall apply to any omission in the contract that may occur.

CD-ROM

CONTENTS

The attached CD-ROM contains additional material to Chapters 2, 3, 7, 10, 11, 18, 21 and 22 of this book. The additional material is cited in the chapters. A file listing the complete contents of the CD-ROM can be found in the directory GENERAL in RTF and PDF formats (GENERAL/CD_CONT.RTF or CD_CONT.PDF).

FILE ORGANIZATION

For each chapter with supplementary material, there is a subdirectory/folder (e.g. /CHAP_02/). Supplementary text is found in (taking Chap. 2 as an example) SUPPL_2.PDF, figures in FIGS_2.PDF and tables in one file for each table (TAB_2_A.PDF etc.).

Chapters 20 and 21 present a model and modelling results in PowerPoint files, which are also available as PDF files.

Installation programs for Acrobat Reader (for reading PDF files) and PowerPoint Viewer are included in the directory PROGRAMS. If there are problems, it is also possible to download installation programs from the Internet. For details, see the README file (README.TXT or README.HTM) on the CD-ROM.

CONDITIONS OF USE AND TERMS OF WARRANTY

see previous pages

SYSTEM REQUIREMENTS

see back cover