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Assessing climate change impacts in the European north

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Abstract Global climate change and its regional manifestation will result in significant impacts in the European North. However, in order to determine the consequences of such impacts, a holistic, integrated assessment is needed. This paper sets the stage for the remainder of this volume by describing an attempt to derive such an assessment for the Barents Sea Region through the EU-funded BALANCE project. The paper explains some of the major methodologies employed in the study. It also provides insight into major results obtained and attempts to answer a number of overarching questions. It will be shown that climate change does present a significant threat to environmental and societal integrity in the study region. However, it will also be shown that stakeholders regard other drivers of future changes (economical, political developments) at least as equally important for their personal lives.

1 Introduction and background

Global climate has been changing ever since Earth's formation and the development of an atmosphere. The last century, however, has witnessed a variation in climate that is unprecedented in at least the past one million years of Earth's history. The distinctive character of these changes lies primarily in the rapidity of climate variations and – to a somewhat lesser degree- in their magnitudes.

Figure 1 illustrates the dramatic change in mean temperatures for the last 100 years relative to the preceding 900 years (upper panel). While the 40-year-smoothed temperatures vary by about ±0.3°C, the last 100 years have seen an almost continues increase in mean global temperatures by about 0.9°C (Houghton et al. 2001). The lower panel of Fig. 1 depicts the spatial distribution of temperature changes over the last 100 years. It is obvious

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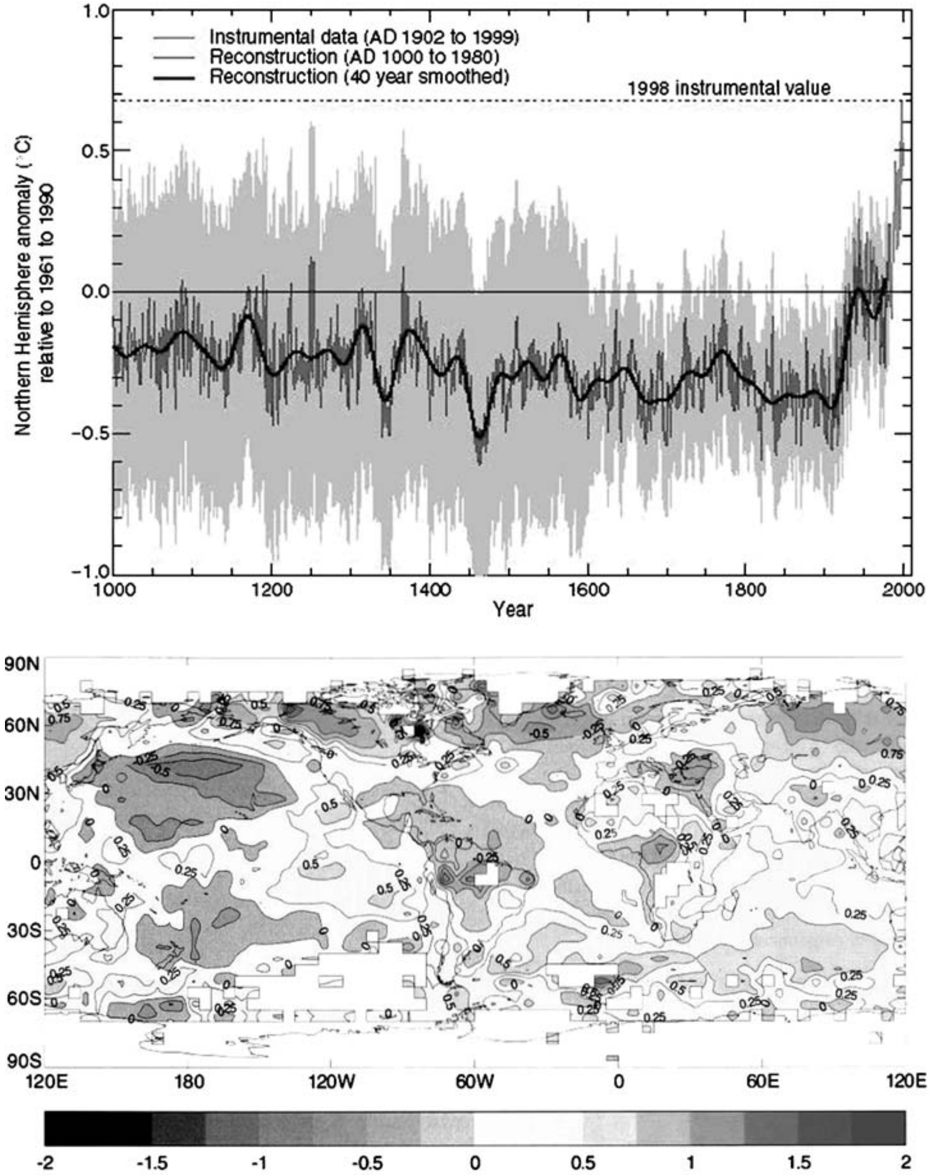

Fig. 1 Deviations of measured and reconstructed (from various proxy records; *top*) mean global temperatures relative to the 1961–1990 mean for the last 1,000 years (see Houghton et al. 2001 for an overview) and spatial distribution of mean temperature changes for the last 100 years (*bottom*), relative to the 1961–1990 mean (after Houghton et al. 1996); additional details, see text

that these changes are quite unevenly distributed across the Earth's surface. A closer look reveals that most of the northern high latitudes have experienced higher magnitudes of warming over the depicted period than the rest of the globe.

This trend has been observed more pronouncedly and even more consistently on the basis of instrumental records throughout the northern hemisphere (Chapman and Walsh 1993 and pers. comm.). Both, detailed observational evidence as well as extensive modelling studies demonstrate that complex feedback mechanisms involving snow and ice covers of the high latitude regions contribute to what has been called “polar amplifications” of climate change (see, e.g., Holland and Bitz 2003; Polyakov et al. 2002). One of the most prominent feedbacks involves the change in the extent of the sea ice cover and its influence on the local to regional radiation budget. An initial retreat of sea ice will expose open water patches with a significantly lower albedo than the surrounding ice. This will lead to more absorption of solar energy, an increase in water temperature and an enhanced heat flow from the water to the overlying atmosphere, which will give rise to further warming. Finally, enhanced warming will create more open water and the feedback loop is closed.

The recently completed Arctic Climate Impact Assessment (ACIA) has provided ample evidence for the latter process (Fig. 2) as well as for other impacts of recent warming on the circumpolar system (ACIA 2005).

ACIA primarily attempted to shed light on the overall consequences of such impacts on Arctic residents and Arctic nature. However, the study –as many others before- fell somewhat short in providing a more comprehensive and/or quantitative appraisal as to the link between changes in external conditions (climate), ensuing changes in environmental properties or the degree of changes in ecosystem services (i.e., the amount of natural resources available for

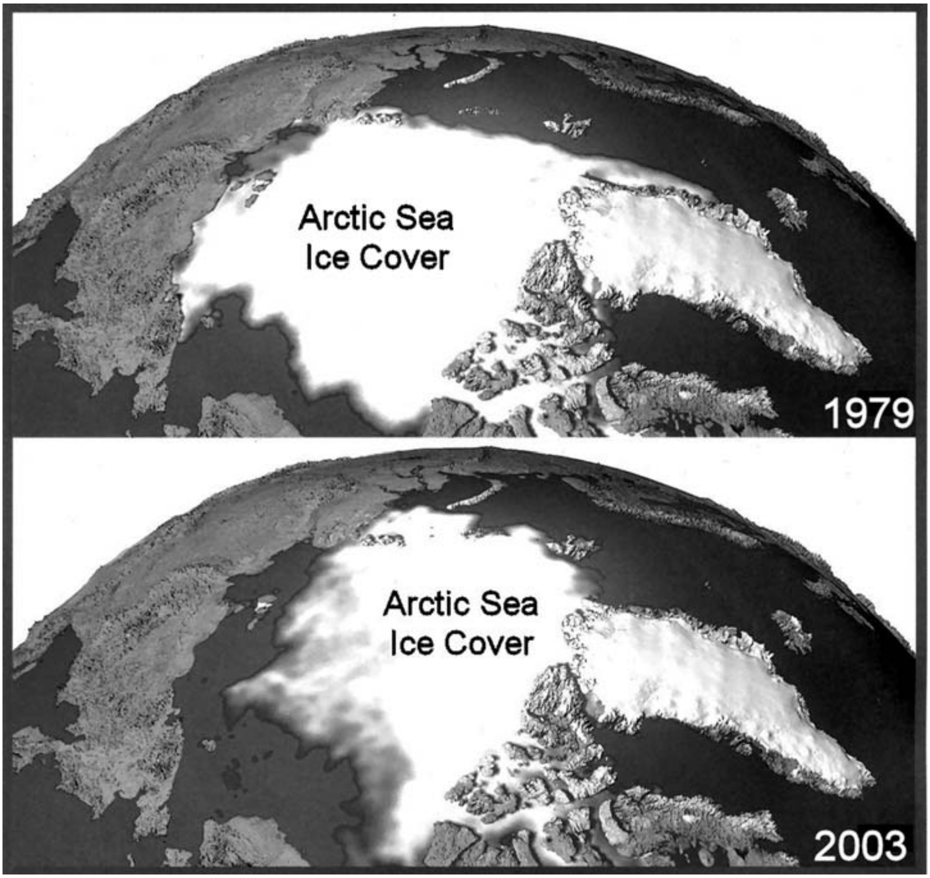

Fig. 2 The reduction in the extent of the sea ice cover for the summers of 1979 and 2003 as derived from passive microwave satellite data (modified after ACIA 2005)

human use) and the resulting repercussions for specific economic sectors depending on these services. It is the latter issue and its consequences for society and societal development, which is most important for political and economical decision makers and the public alike.

Furthermore, despite some regionalization ACIA adopted a circumpolar scale in the assessment. It is known, though that climate change becomes manifest on a distinctly regional to sub-regional scale. This implies impacts on a similarly sub-regional scale. In addition, and as now broadly accepted, climate impact assessments have to account for the complex interactions between individual components of the region under consideration and have therefore to pursue an interdisciplinary research strategy.

Therefore, in order to understand and quantify the holistic nature of regional to sub-regional climate change impacts, methodologies known as integrated regional impact studies (IRISs) have been developed and applied (see, e.g., Lange 2000b). Such studies compare the course of future development of a region under two conditions: (i) by ignoring any change in climate and by projecting present developments of ecosystems and socio-economic systems in a given region (base line scenario) and (ii) by accounting for climate change and its impacts on environmental and socio-economic systems (global change scenario). The differences in the overall development, measured, e.g., by addressing forest productivity and the resulting price of timber or by accounting for the effect of climate change on fish stock and the consequent shift in the fish markets, constitutes the overall impact of climate change for a given region. Figure 3 depicts the general approach taken in an IRIS (or more basically, in an integrated climate change impact assessment – regardless of scale), which includes a few additional components (cf., Lange 2000b).

In particular, non-climatic drivers of change in a given region (i.e., the likely development in demographic, technological and economical development) and estimates of climate change over the length of the study period have to be provided. The latter may be based either on a global model or –preferentially- on a regional-level numerical climate model.

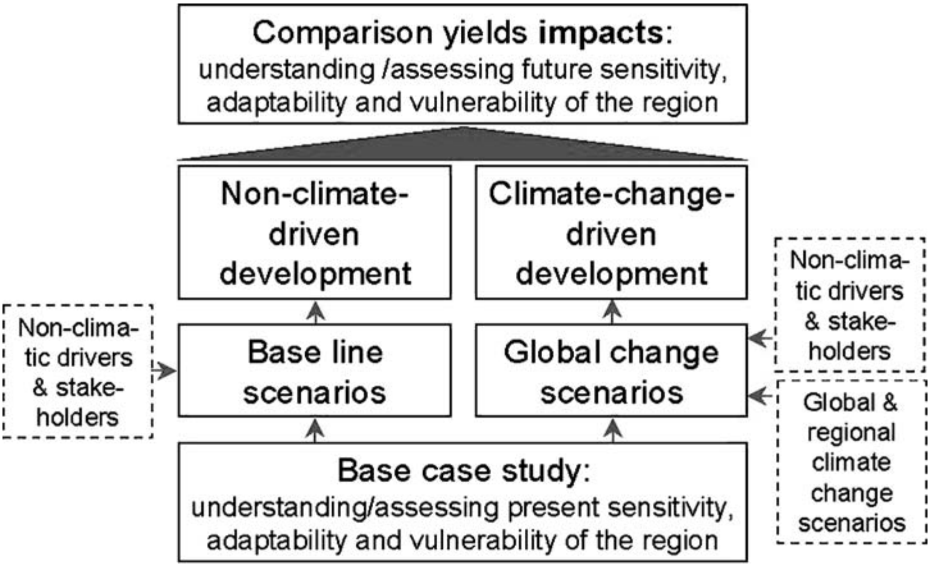

Fig. 3 Schematic depiction of the major elements of an integrated climate change impact study and the sequence of steps within an impact assessment

Figure 3 contains three terms that are commonly used in the *impact assessment* literature, but need to be defined here as follows (after Smit and Pilifosova 2001):

- *sensitivity* describes the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli; the effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise);
- *adaptation* to climate change refers to adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities; various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, as well as autonomous (i.e., intrinsic to the system under consideration) and planned adaptation (i.e., adaptation measures initiated through human activities);
- *vulnerability* represents the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes; the vulnerability of a given system is a function of the character, magnitude, and rate of climate variation to which this system is exposed, its sensitivity, and its adaptive capacity.

In the following, we will describe an IRIS that has been carried out for the Barents Sea Region in the European North with the aim to assess vulnerabilities of the region to climate change over the next 20 to 100 years.

2 The BALANCE project

2.1 Brief history - Barents Sea impact study

The BALANCE project (Global Change Vulnerabilities in the Barents Region: Linking Arctic Natural Resources, Climate Change and Economies) has its root in initial considerations and discussions of the Global Change Working Group (GC-WG) of the International Arctic Science Committee (IASC). Early on, it was decided to carry out two impact studies in the Circumpolar North (Kuhry 1994), one in the Barents Sea Region, Barents Sea Impact Study (BASIS) and one in the Bering Sea Region, Bering Sea Impact Study (BESIS). Subsequently, BASIS and BESIS (Weller and Anderson 1998; Weller and Lange 1999) were developed as Priority Projects of IASC. BASIS was supported by the European Commission and resulted in a number of important new findings, which have been reported in numerous publications (Berlin 1999; Berlin and Piepel 1999; Cornellisen et al. 2001; Gjøsæter et al. 2002; Harding and Lloyd 1998; Kozlov and Barcan 2000; Kozlov et al. 2000, 2001; Kuhry and Lange 1997; Lange 1999, 2000a; Lange et al. 1999; Lange and BASIS consortium 2003; Layton 2000; Layton and Pashkevich 2000; Layton and Wiberg 2000; Mariussen and Heen 1999; Vitebsky 1999; Wassmann et al. 1999; Wiberg 1999; Zvereva and Kozlov 2000, 2001).

Already in 1990 and prior to BASIS and BESIS, one of the first IRISs ever conducted in the circumpolar North, the *Mackenzie Basin Impact Study* (MBIS), had been initiated in Canada (Cohen 1997). Since known to IASC, the results and experiences gained in MBIS were reported at the IASC conference on Arctic Research Planning in Dartmouth, USA in 1995. This formed the basis for fruitful collaboration between the two IASC projects and MBIS.

Despite the wealth of new information generated, we felt that BASIS had provided only the first steps in a full IRIS. In particular, while individual impact models had been developed as part of BASIS (e.g., with regard to the marine ecosystem or related to smaller-scale hydrological processes in northern Finland), the link between these models and a more integrated model package designed as an integrated assessment model (IAM) remained to be implemented under a new project called BALANCE.

Thus, we decided that we should continue to work on the problem of climate change impacts in the Barents Region with a new emphasis on linking individual impact models and a dedicated regional climate model (in the following called BALANCE-RCM) and to build up an IAM for the study region. This then led to the formulation of a new project plan and –after obtaining funding from the European Commission- to the initiation of the BALANCE project (EVK2 – 2002 – 00169).

2.2 Rationale/objectives

The overall goal for BALANCE has been to *assess the vulnerabilities of the Barents Sea System (BSS) to climate change based on a common modelling framework for major environmental and societal components and on the quantification of linkages between these components.*

The main emphasis of BALANCE lies on:

- the identification and quantitative (model) description of major components of the BSS;
- the identification and quantitative characterisation of linkages and interactions between these components; and on
- deriving vulnerabilities of the BSS to climate change through considerations of climate change and baseline scenarios, the former being derived from a dedicated regional climate model.

The major goal of BALANCE has been addressed through various specific objectives, which follow the steps depicted in Fig. 3 and were addressed in a number of sub-projects within BALANCE.

Figure 4 depicts schematically the major elements of the BSS as well as the linkages and interactions between them as addressed in the project. As can be seen, we consider the BSS based on three distinct levels depicting societal processes, resource-based economies/ecosystem services and environmental components and processes. Individual components within each level are interrelated, as are components on different levels within the system. On the environmental level, all components are mutually related, i.e., processes in one component have a bearing on each of the other components. The three economic sectors that are depicted on the resource-based economy level depend primarily on processes and changes in terrestrial and marine ecosystems. While forest based activities often compete with reindeer husbandry, fishery activities are not directly linked to either of these sectors. However, all economic activities are –one way or the other- determined by national and international policies and regulations such as fishing quota, forest harvest regulations or legal provisions related to the slaughtering of reindeer. Societal processes (e.g., migration) and socio-economic determinants (e.g., consumer preferences) will be influenced by resource-based economies and will conversely determine the course of such activities in northern communities.

The exact specification of these links and relationships and their formalization/quantification in the context of an IAM comprised one of the most demanding tasks within BALANCE.

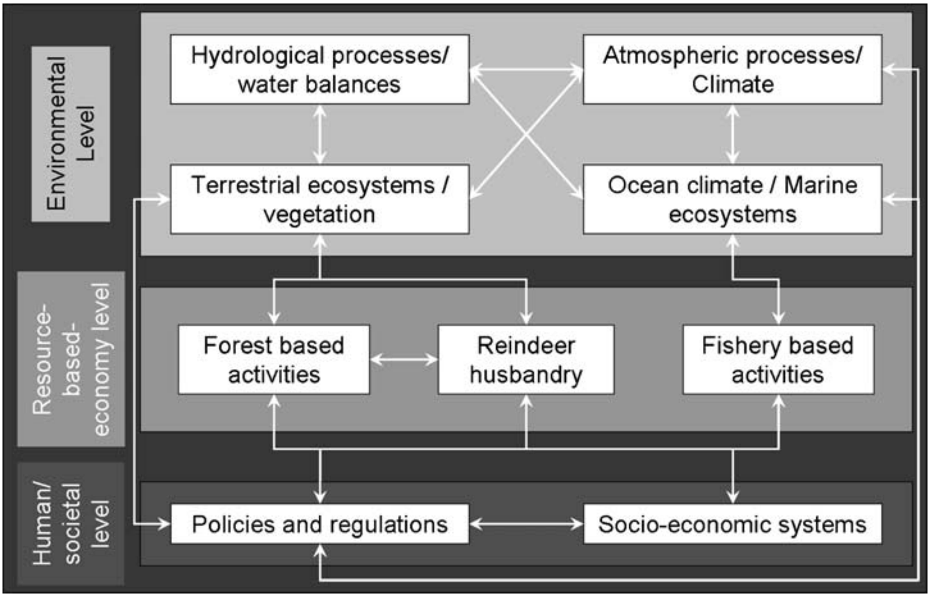

Fig. 4 Major components of the BSS and some of their linkages/interactions as considered within BALANCE; *black arrows* depict links within each level, *white arrows* relations between different levels

In designing the IAM to be employed in BALANCE, we pursued two basic concepts:

(i) a full/comprehensive IAM which aims at quantifying all or most of the components and linkages as depicted in Fig. 4 in a single model and
(ii) an integrated assessment model of intermediate complexity (IAM-IC), which depicts a selection of the components and linkages in order to address specific questions related to the impact assessment of climate change.

More details of these concepts and of some of the individual models employed in BALANCE will be provided below.

BALANCE has been designed and carried out with a strong focus on the involvement of stakeholders. This was motivated mainly by the following objectives:

- to determine how stakeholders perceive climate change in their present life;
- to elucidate the role of climate change from the perspectives of local residents in comparisons to other determinants of future development (political, economical, societal);
- to explore mitigation and adaptation strategies that local residents have utilised in the past and those that they envision in light of future climate change impacts.

These aspects and selected results of our investigations are considered in the remainder of this paper as well as in a separate paper by Keskitalo (2008).

2.3 Overall approach

The overall approach taken in BALANCE may best be described graphically. Figure 5 illustrates the major elements and major activities to be carried out in BALANCE.

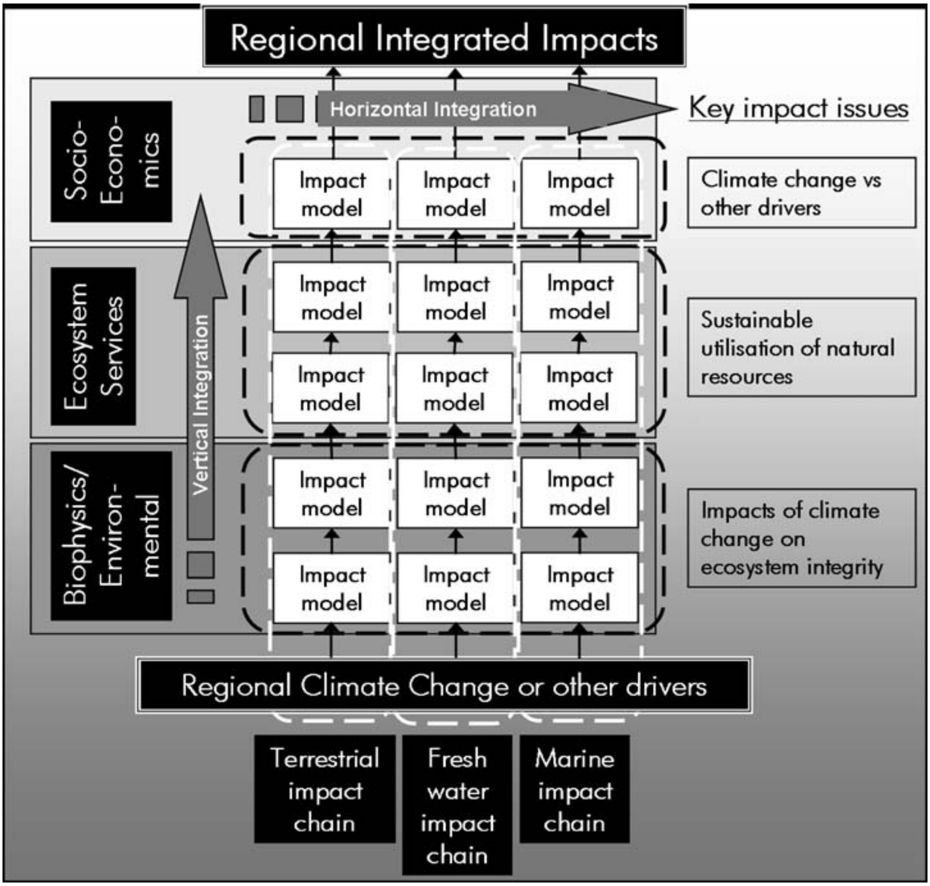

Fig. 5 Schematic diagram depicting the general approach to integrated impact assessments adopted in BALANCE; for additional details, see next section

The three main compartments correspond to the three levels of the BSS as depicted in Fig. 4. Each compartment comprises a number (usually less than shown in the figure) of impact models. Impact models describe and quantify the response of particular components within the compartment to climate change (other, non-climatic drivers may also be taken into account, where appropriate). Typical examples include: a forest growth model, a fish stock model or a model describing the response of the fishing industry to diminishing fish stock sizes. Vertical integration is carried out along so-called impact chains, which sequentially link the impact models in each compartment across all compartments within specific domains, i.e., the terrestrial, marine and fresh-water domain. The impact models are chiefly driven by the BALANCE-RCM as well as by other (non-climatic) drivers. At the end of the impact chains, aspects of the integrated regional climate impact pertaining to each of the domains are being obtained. In addition, horizontal integration utilizes the results of the impact models within a given compartment in order to address overarching key impact issues. The ones given in the figure are only a short-hand for more comprehensive questions, which will be addressed below.

2.4 Scope

The overall scope of the BALANCE analyses/models can be summarized as follows:

- the study region of BALANCE comprises northern Fennoscandia, the northern parts of the Kola Peninsula and large fractions of the Arkhangelsk Oblast, Russia and is depicted in Fig. 6;
- within the study region, we address the following components of the BSS (cf. Fig. 4):
- environmental: terrestrial ecosystem, marine ecosystem, fresh-water ecosystem;
- climate development: through a dedicated RCM for the wider study area;
- societal/socio-economical: forestry, fisheries, reindeer husbandry[1];
- the modelling employs a common scale of about 50 km or less;
- a seasonal (monthly) temporal resolution around one or two time slices at 2020, 2050 and 2080 with integration over ±20 years around this time is realized in the models;
- stakeholder input and policy analysis have been carried out in order to assess other (non-climatic) factors affecting overall vulnerabilities of the BSS.
- Major stakeholders considered in the Arctic in general and in BALANCE in particular comprise:
  - *Arctic residents*, including the general public with interest in the quality of life and the integrity of the environment, in economic development and the labour market and in education and training. This group also includes sectoral interest groups, e.g., those representing the fishing, the aquaculture or the timber industry, but also those concerned with conservation, recreation and tourism. A group deserving particular attention are the indigenous communities and their representatives.
  - *Resource managers*, i.e., individuals or groups of private industry involved in the utilisation of natural resources of the Barents Sea Region.
  - *Scientists* involved in research on the impacts of climate change in the Arctic.
  - *Policy makers* at the local (municipal governments in the North), regional (e.g., the Barents Euro-Arctic Council) and global level (the Arctic Council) represent stakeholders that are immediately concerned with global change impacts in the Arctic and in the Barents Sea Region.
  - The *global community* outside the Arctic, which may be affected by global changes in the Arctic as well as the scientific community.

2.5 Major components of the BALANCE project

BALANCE has been carried out on the basis of four work packages (WPs):

○WP1: Vulnerability of marine ecosystems
○WP2: Vulnerability of terrestrial ecosystems
○WP3: Vulnerability of socio-economic systems
○WP4: Integration, modelling, stakeholder involvement, co-ordination and dissemination

Each of the WPs will in the following briefly be described.

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[1] While we are well aware of the fact that reindeer husbandry may not be seen as a sector of equal importance as forestry and fisheries, we are convinced that the significant value, both economically and culturally of this activity for the Sàmi and the Nenets, who are both resident in the BALANCE study region warrants the inclusion of this sector into the research agenda; in addition, reindeer herding provides a crucial link between flora and fauna of terrestrial ecosystems in the Barents Sea region.

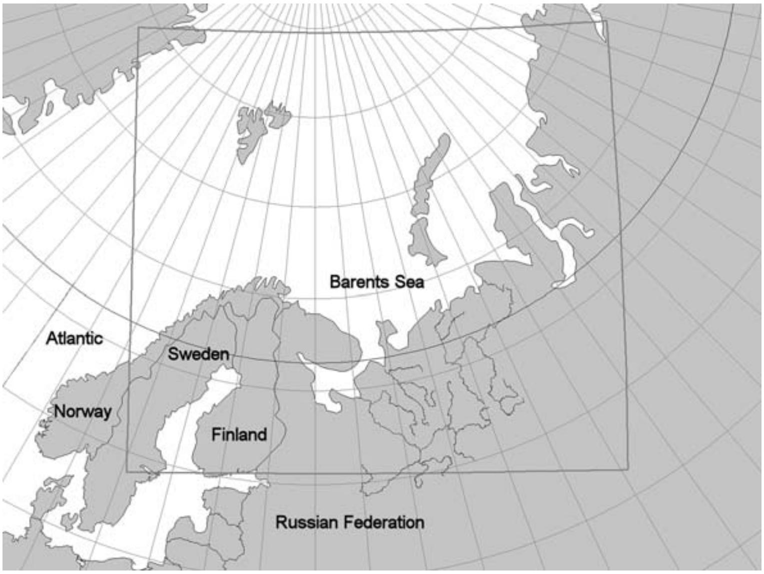

Fig. 6 Simplified map of the Barents Sea region and the study region (*outlined figure*), which is also the modelling domain for the RCM

2.5.1 WP1: Vulnerability of marine ecosystems

Activities in this WP concentrated on relating large-scale changes in oceanic conditions (e.g., variations in the inflow of Atlantic water, atmospheric temperatures, variability of the sea ice cover, riverine input) to the physical structure and the biological productivity of the water column in the Barents Sea. Through a dedicated 3D-ocean model, driven by the regional climate model, the vulnerability of primary and secondary production in relation to these changes has been appraised.

The model results have–at least in part- been utilized in assessing the fate of major fish stocks in the Barents Sea. In addition, statistical data spanning several decades of sampling and specifically designed fish population models were used to determine the fate and migration patterns of key fish species. Based on a suite of model components but also employing results of the other sub-projects within WP2, consequences of climate change on the Norwegian fishery industry have been investigated.

2.5.2 WP2: Vulnerability of terrestrial ecosystems

This WP focuses on the assessment of the vulnerability of the terrestrial ecosystem to global climate changes in the study region. This was achieved through a series of linked numerical models describing the responses of vegetation, forest pests and diseases, reindeer herding and hydrology to climate variations. In addition, a detailed study on possible shifts in terrestrial (and marine) biodiversity as a result of recent climate/global changes in the Arctic was carried out. Six sub-projects employed field investigations, various statistical and archival studies as well as a suite of individual models describing particular components and processes of the terrestrial system in the BSS. A major emphasis was laid on the (quantitative) link between individual models in order to determine the present vulnerability of terrestrial ecosystems in the study region (Fig. 7).

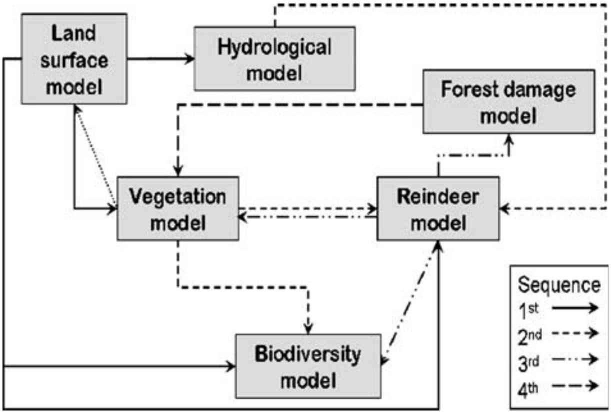

Fig. 7 Diagram depicting the connections between individual models and the sequence of their linkage in WP2 (after Callaghan, pers. comm.)

Similar to WP1, the major driver for these models are the climate scenarios for the study region as derived from the BALANCE-RCM (not shown in Fig. 7 but implicitly assumed for each model). The land surface model yields soil temperatures and soil moisture for the upper 0.1 m as well as snow cover characteristics. These results are utilized in the hydrological model, the Biodiversity model, the Vegetation model, and the Reindeer model. The hydrological model, which aims to assess the water balance of the Barents Sea drainage basin, utilizes evaporation, soil moisture and snow cover data to derive runoff and drainage and ultimately the river flow to the Barents Sea (for more details, see Dankers and Middelkoop 2008). Snow cover characteristics are also essential inputs to the reindeer and the biodiversity models.

The vegetation model requires evaporation, soil moisture and snow cover data to determine changes in species composition and biomass in the study region. The vegetation and the hydrological model provide vital inputs to the reindeer model, i.e., the availability and amount of food for the reindeer. This includes information of ice layer formation in the snow pack, which is an essential parameter for winter-feeding. The reindeer model yields information on reindeer feeding in forested areas, which is an important boundary condition for the forest damage model. This model determines the extent and magnitude of forest damage through insect pests and estimates forest growth in the study region. These results are input into the vegetation model and results in modified vegetation distributions. These are finally fed back to the land surface model and serve as new boundary conditions for a repeat run of the model. More details and results can be found in various individual publications in this volume.

2.5.3 WP3: Vulnerability of socio-economic systems

Socio-economic systems in the high-latitude Barents Region have long been acknowledged as being highly sensitive to climatic fluctuations. Their vulnerability to possible impacts of global warming is therefore a serious issue for research, particularly where the economy and ways of life are closely dependent on natural resources. Directly or indirectly, forests, fisheries, aquaculture and reindeer herding provide the means of livelihood for a significant part of the population. Thus, the assessment of impacts of global climate change on these sectors was a common goal for the sub projects of this workpackage. This was done by addressing fishery economies (also as part of WP1) for the northern parts of Norway and by looking into the prospective changes in employment in the forestry sectors as a result of climate change in three localities in the Barents Sea Region (Norrbotten in Sweden, Lapland in Finland and the Arkhangelsk Oblast in Russia).

2.5.4 WP4: Integration, modelling, stakeholder involvement, co-ordination and dissemination

WP4 was the most complex of the WPs in BALANCE. It included activities that reached from the BALANCE-RCM over data handling and dissemination and stakeholder involvement to the integrated modelling carried out in BALANCE. Aside from the already mentioned integrated assessment modelling (section 2.2.), two additional integration methodologies have been employed: (i) an Assessment and Decision Support System (ADSS); this system combines qualitative and quantitative analyses by utilizing the BALANCE Spatial Data Infrastructure and Geographical Information System (GIS; see Bernard and Ostländer 2008); (ii) an impact assessment which directly addresses ecosystem responses to climate change and utilizes a GIS to derive maps of potential impacts; the maps may subsequently lead to integrated interpretations and vulnerability analyses (for more details, see Roderfeld et al. 2008).

The BALANCE-RCM is the regional climate model (REMO) of the Max-Planck Institute for Meteorology in Hamburg, Germany (for more details, see Jacob 2001; Jacob and Podzun 1997; Göttel et al. 2008 and below). Boundary conditions for REMO at the edges of the model domain (cf., Fig. 6) are specified based on the transient ECHAM4/OPYC3 global climate model (GCM), which is driven by the SRES B2 scenario of the Intergovernmental Panel on Climate Change (Nakicenovic et al. 2000).

The exchange and distribution of data and information was accomplished through various web-based services. Via the general web-site (http://balance-eu.info), which basically served the needs of the project participants and the scientific community, a dedicated stakeholder portal is accessible, which offers not only information on the project, its background and results but also an opportunity for stakeholders to take an active part in BALANCE.

The involvement of stakeholders was an important element in BALANCE. Mainly through literature surveys, stakeholder interviews and stakeholder meetings, the perception and understanding of climate change and its effects on the local to regional level have been discussed and investigated with residents and decision makers (Keskitalo 2008 and below). A major component of this WP has been the integrated assessment modelling (see above).

In the following, we will briefly describe some of the basic methodological approaches taken in BALANCE before discussing major findings.

3 Methodologies

Even the attempt to describe the methodologies employed in BALANCE in a single chapter seems futile, given the fairly complex nature of even a single impact model. Thus, the following sections merely aim to provide brief introductions into major methodological approaches and cannot replace the more complete descriptions provided in the individual papers contained in this volume.

3.1 Impact models

As mentioned above, impact models depict the response of particular components within each of the three compartments of the BSS considered (cf. Fig. 4). In total, about 9 impact models (Table 1) were employed in BALANCE. They reached from highly complex models, almost representing integrated models in their own right, e.g., the 3D ocean model (cf. Fig. 8, Slagstad et al. 1999; Slagstad and McClimans 2005; Slagstad and Wassmann 1997) to relatively simple models, e.g., a spreadsheet-based forest growth model (Kozlov, pers. comm.).

As already mentioned, most of these models have been driven by the climate scenarios derived from the BALANCE-RCM (see below). Additional details can be found in subsequent papers in this volume.

3.2 Regional climate modelling

Carrying out a climate impact study requires the provision of suitable climate scenarios for the time span under consideration. If the assessment takes place on a regional scale, it is necessary or at least advisable to utilize climate scenarios on a similar scale. Since global climate models (GCMs) are currently not being run on such scales, some kind of "downscaling" is necessary. While various methods can be employed (for an overview on methods, see, e.g., Giorgi et al. 2001), we decided to develop and utilize a dedicated regional climate model (see above).

Table 1 Main impact models employed in the BALANCE project

Work package	Model name	Brief description
WP1: Vulnerability of marine ecosystems	SINMOD	Coupled physical-biological model to determine temperature, salinity and sea ice distribution as well as primary and secondary production and the CO2-budget in the Barents Sea
	Capelin IBM	Individual-based model to derive Capelin distribution, growth and biomass in the Barents Sea based on (varying) physical boundary conditions provided by SINMOD
WP2: Vulnerability of terrestrial ecosystems	JULES	Joint UK Land Environment Simulator; land surface model based on MOSES (Met Office Surface Exchange System)
	BarentsFlow	Spatially distributed hydrological model used to estimate river runoff and riverine discharge to the Barents Sea in the Barents Region
	TanaSNOW	Energy budget snow module as part of BarentsFlow
	LPJ-GUESS	Lund-Potsdam-Jena dynamical vegetation model used to estimate changes in the spatial distribution of plant functional types in response to climate change
WP3: Vulnerability of socio-economic systems	Employment modifier	Estimation of forest-related employment as a function of variable forest growth rates resulting from changing climate
	ECONSIMP 2000	Fisheries model system including SINMOD (physical/ocean model), AggMult and EconMult
WP4: Integration, modelling, stakeholder involvement, co-ordination and dissemination	REMO	Regional climate model of the Max-Planck-Institute for Meteorology, Hamburg, Germany based on former weather prediction model of the German Weather Service

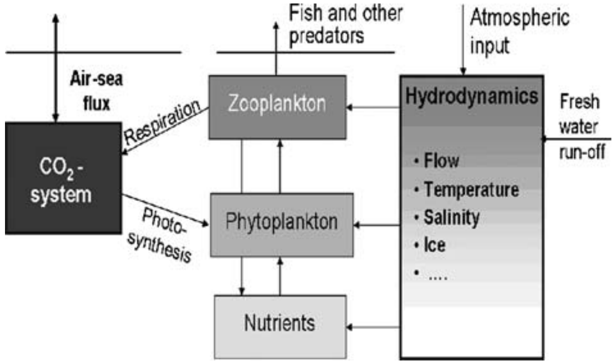

Fig. 8 Schematic representation of the 3D-ocean model system comprising a hydrodynamics module that is driven by climate scenarios and riverine input data (*right*), a module determining the distribution and development of nutrient concentrations as well as phytoplankton and zooplankton concentration and composition (*center*) and a geochemical module assessing the CO2-concentration in the water column as a function of zooplankton respiration, phytoplankton photo synthesis and air-sea fluxes (*left*) at the surface of the ocean (after Slagstad, pers. comm.)

Figure 9 gives a few selected results of the REMO runs. As can be seen, climate change leads to a warming of up to 7° for the entire study region (i.e., there are only positive values of temperature differences shown in the figure) with magnitudes gradually increasing in time. Another observation is the enhanced warming during the winter months relative to the summer months of each time slice. These findings agree well with other published modelling results (see, e.g., ACIA 2005).

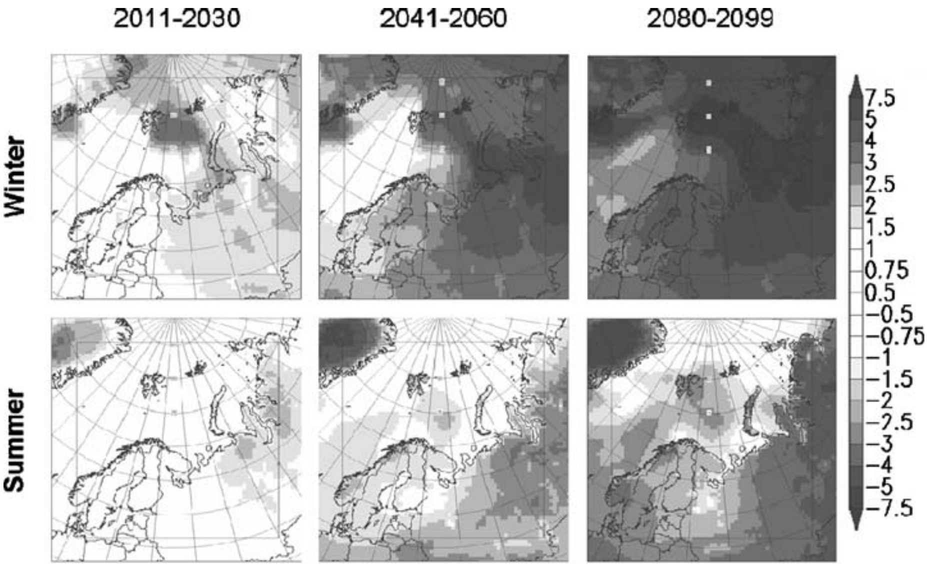

Fig. 9 Simulated near-surface air temperature differences for selected time slices (as indicated on top of *panels*) versus the control period (1981–2000) for winter (*top row*) and summer (*bottom row*); after Göttel et al. 2008

3.3 Integrated assessment model of reduced complexity

As mentioned above, the linkages between individual component models describing the BSS was a major objective of this study. While initially intended, we decided not to realize a full IAM involving all of the models utilized in BALANCE. Instead, we opted for the second approach mentioned above (section 2.3), i.e., an integrated assessment model of reduced complexity (IAM-RC). Figure 10 depicts the initially envisioned major elements of the IAM-RC.

As can be seen, the IAM-RC addresses exclusively terrestrial processes/components of the BSS. The rationale for leaving out the marine realm lies in the fact that the models developed and employed in WP1 (see above) can already be considered somewhat of an IAM in their own right (cf. Fig. 8). While it would have been advantageous to include marine processes in the IAM-RC, we had to weigh the enhanced complexity of such a model versus the feasibility of the attempt to build an IAM and therefore decided not to pursue this inclusion. An additional reason for calling our model an IAM of reduced complexity lies in the somewhat simplistic structure of our model design. We neglected, e.g., feedback between reindeer growth and vegetation cover.

In the following, a few selected results of the IAM-RC will be presented. Figure 11 shows the spatial extent and distribution of birch and coniferous forest covers for the years 1990 and 2080. In summary, the net effect of climate change in the Barents Sea Region is a decline in birch forest concentrations from highs of around 60% cover in 1990 to no more

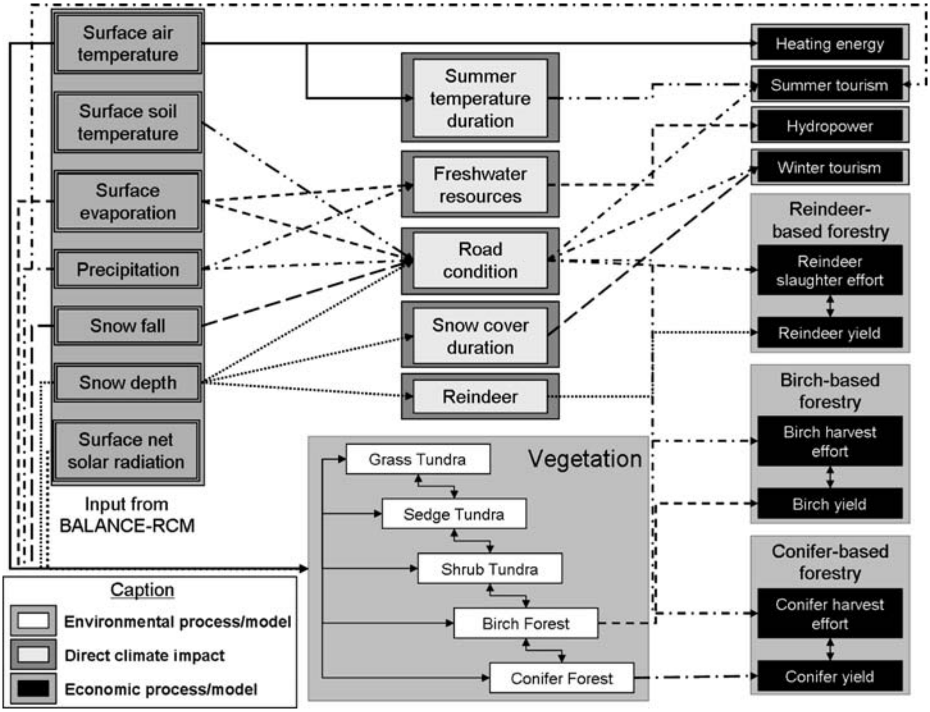

Fig. 10 Schematic depiction of major components of the IAM_RC employed in BALANCE and their relationships/dependencies (unpublished results)

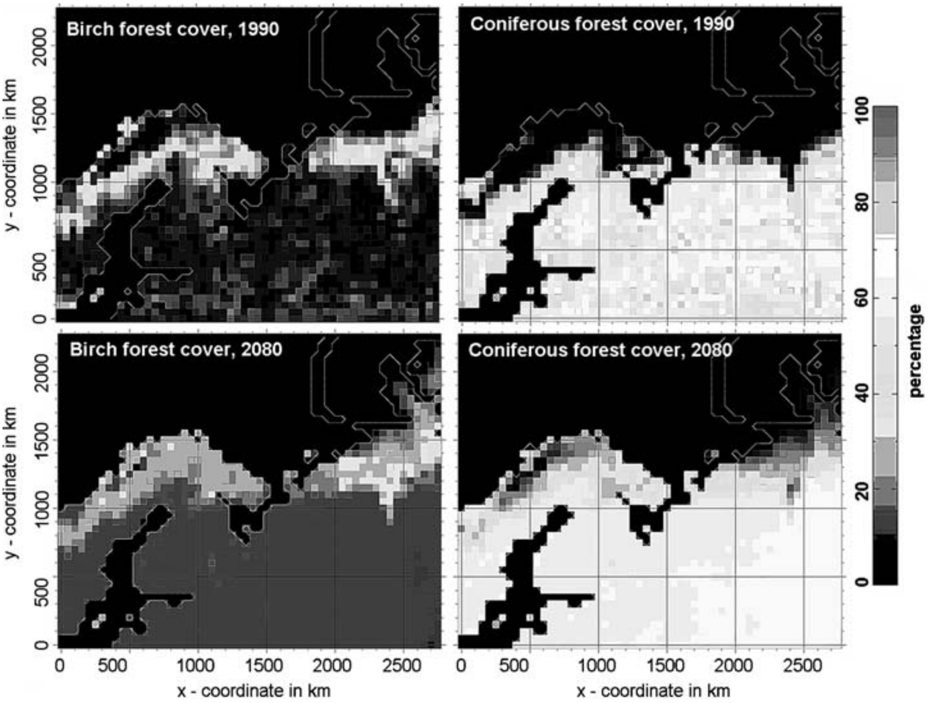

Fig. 11 Simulated distribution and spatial concentrations of birch and coniferous forests in the Barents Sea Region for 1990 versus 2080; all values shown lie below 80%, i.e., only the lower two-third of the scale is applicable (unpublished results)

than 40% in 2080 with birch being found at approximately the same positions in 2080 as compared to 1990. Conversely, while coniferous forest covers do not significantly increase in concentration per unit area, they increase in extent and cover all of northern Scandinavia in 2080, where previously (1990) no conifers were found.

Figure 12 illustrates two aspects of regional climate change that are usually not or only insufficiently treated in an IRIS. As can be seen, winter tourism is projected to decline by 20 to 40% in 2080, while the consumption of energy for heating also decreases by up to 25% in 2080.

While our model is still in its infancy, we believe that its results such as shown in Fig. 12 will be most instructive in discussions with stakeholders and decision makers. Quantities such as the shifts in dominant (harvestable) tree species, the declining extent of winter tourism in northern Fennoscandia and the reduced need for heating energy by 2080 have direct economic implications. These issues were also discussed with stakeholders as part of the project as described below.

3.4 Stakeholder involvement

As mentioned above, the involvement of stakeholders and the integration of their experiences and expertise was a major objective in BALANCE. The basic means to pursue this were interviews with various individuals on the village level but also with local and regional decision makers as well as stakeholder meetings that took place throughout the study region (Fig. 13).

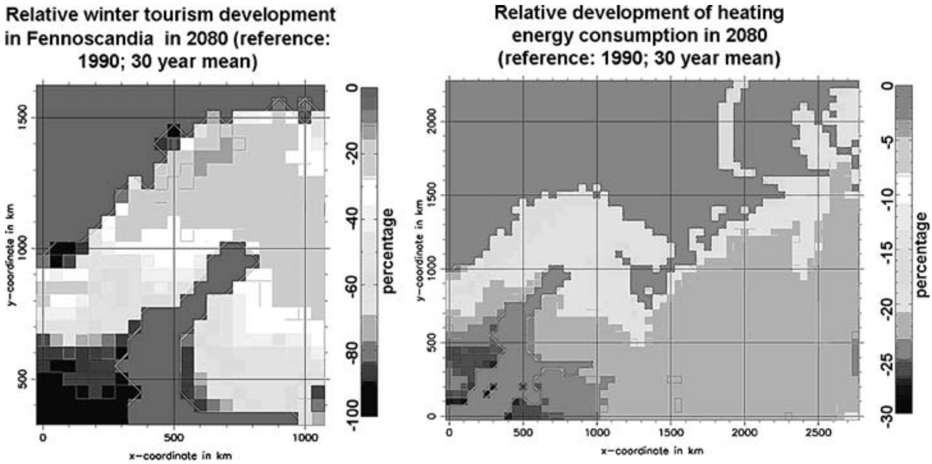

Fig. 12 Simulated changes in winter tourism in Fennoscandia (*left*) and in the demand for heating energy (*right*) by 2080 (note the different scales; unpublished results)

In the interviews, individuals were asked to express their opinion regarding the current economic, political and environmental state, their expectation as to changes in these fields and their opinion related to possible adaptation options. In particular, stakeholders and decision makers were asked to express their view as to the relative importance of environmental and climate change versus changes in economical and political boundary conditions (for more details on methodology, see Keskitalo 2008). Almost all interviewees voiced their concern about recent economic changes that had a significant bearing on their daily life, in particular, an economic restructuring including an ongoing internationalization in their fields of activity (primarily forestry as well as the pulp and

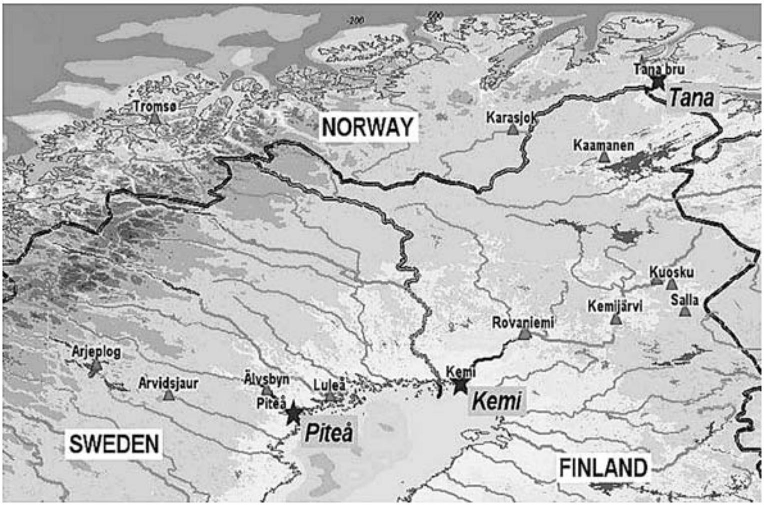

Fig. 13 Map showing northern Fennoscandia and the locations of stakeholder interviews and/or meetings; note that most locations are situated along the river valleys of the Piteå, Kemi and Tana river (after Keskitalo, pers. comm.)

paper industry, fisheries, reindeer herding) and the continuous decoupling of economic activities from the local level, i.e., a growing influence of globalization on their way of life.

With regard to the current political situation, stakeholders and decision makers emphasised the view that while most decisions are being made on the national level, there are regulations on the European or even the international level that are important for their communities on the local level. This includes, e.g., the ILO (International Labour Organisation) Convention No. 169, which has a bearing on reindeer herding activities, fishery quotas on the European level, which limit fishing activities since the 1990ies and land rights or voluntary regulations, such as the NATURA 2000 convention regarding forestry activities.

When confronted with various climate change scenarios and their possible impacts (e.g., earlier springs or springs that shift in time, warmer and drier summers, later autumns or milder winters with possible repeat thawing periods), the response of interviewees differed according to the main economic activity they pursued. However, in each case, there were both positive and negative aspects that were seen by the stakeholders and decision makers as well as aspects of impacts that pertained to other sectors of the economy and/or to a variety of environmental components. Those in the forestry sector stressed that a longer growing season and increased productivity might be offset by more difficult production conditions. The latter relate primarily to earlier thawing of forest roads, a heavier snow load and resultant enhanced damage to the trees and the invasion of southern species which might have both positive and negative implications. Interviewees mainly involved in reindeer herding stressed that increased thawing- and refreezing events in winter as well as warmer and drier summers, which might change grazing conditions would have more negative than positive consequences. Persons employed in the fishery sector mentioned that climate change could mean increased productivity and increased fish stocks. However, they were also concerned that the migration of southern species into their fishing grounds might change predator-prey relationships with repercussions on harvestable fish stocks. In addition, possibly larger frequencies of adverse weather conditions might have negative impacts on their economic output.

A major lesson learned from the interactions with stakeholders and decision makers lies in the observation that local residents view change more holistically than usually assumed. They do not separate changes in economic and political conditions from those imposed by regional climate change when considering suitable adaptation options. Another important conclusion derived from the stakeholder work is the fact that economic considerations play a major role in decision making on the local or the household level. Climate change is primarily considered with regard to its possible adverse effects on economic activities (more considerations can be found in Keskitalo 2008 and will be presented below).

This brief representation of some of the results obtained in stakeholder and decision maker interviews may suffice to demonstrate that the involvement of stakeholders has indeed proven its irreplaceable value in an IRIS such as BALANCE (for more details, see Keskitalo 2008). While sometimes difficult and time consuming, the contribution of local residents to a broader and possibly more realistic assessment of climate change impacts is –in our opinion- well worth the effort.

4 Main results and overarching issues

While a comprehensive representation of even the most significant results is clearly beyond the scope of this paper, we will address a selected few overarching key impact issues that provide an opportunity to integrate horizontally across the three impact chains considered more by virtue of vertical integration (cf. section 2.3 and Fig. 5). The issues addressed each relate to one of the major compartments/levels depicted in Fig. 5: the biophysical/environmental compartment, the ecosystem-services compartment and the socio-economics- or societal compartment. In so doing, we will briefly describe a few findings that are depicted in more details in other contributions of this volume.

4.1 Impacts of climate change on ecosystem integrity

This issue relates to the effects of climate change on individual components of the biophysical/environmental level (cf. Fig. 5) considered in BALANCE and possible mutual interactions between them. The term “ecosystem integrity” is meant to imply a state of an ecosystem that can be described as being “healthy” and well-functioning. Such an ecosystem is only influenced by climate change to the extent that its individual members as well as their mutual interactions are not permanently damaged. In other words, the ecosystem is capable to mobilize sufficient autonomous adaptation mechanisms to counter initial impacts and thereby minimise vulnerability. In the following, we will briefly examine some of the results of individual impact models in order to assess the level to which ecosystem integrity might be threatened and to what degree the impacts on a particular component of the biophysical/environmental level might have a bearing on other components on this level.

With regard to the impacts of climate change on the marine ecosystems of the Barents Sea, the primary effect will be an increase in mean (near-surface) water temperatures and a decrease in sea ice cover (Fig. 14). A direct effect of these impacts as well as of those seen in terms of the characteristics of Atlantic Water inflow and decreased inflow of Arctic water are changes in biological productivity (for more details, see Ellingsen et al. 2008). As can be seen in Fig. 14, primary production will increase (mostly in the eastern and north-eastern part of the Barents Sea). While Atlantic zooplankton species will increase, Arctic zooplankton abundances will decrease leading to an overall decline in the biomass of zooplankton in the Barents Sea.

Furthermore, while the curves in c) and d) are correlated with the temperature curve in a), the curve in e) seems somewhat anti-correlated with the temperature curve in a) or slightly correlated with the sea ice anomalies in b). These impacts do not -in our assessment- represent a threat to the integrity of the major biophysical characteristics of the Barents Sea ecosystem. However, the changes in zooplankton species abundances and their spatial distribution may have a bearing on major consumers, i.e., fish species in the Barents Sea.

The results of an individual-based capelin model (Huse and Ellingsen 2008) support this assumption. The migration pattern follows the variation in temperature distribution and thus in biological characteristics of the water masses. Thus, capelin feeding migration will likely spread further north and east, following the movement of the Polar Front. Moreover, warmer water temperatures lead to an earlier spawning of capelin by about 1 month. This will have consequences for ecosystem integrity, as it affects the entire life cycle of this important species. It will also affect the cod stocks that will follow the capelin to the North and East of the Barents Sea. However, at present these effects are not quantifiable.

While changes and impacts in the marine realm will have little consequences for terrestrial ecosystems, changes in the terrestrial domain will have consequences for the Barents Sea. This applies particularly to the freshwater input by the rivers draining the

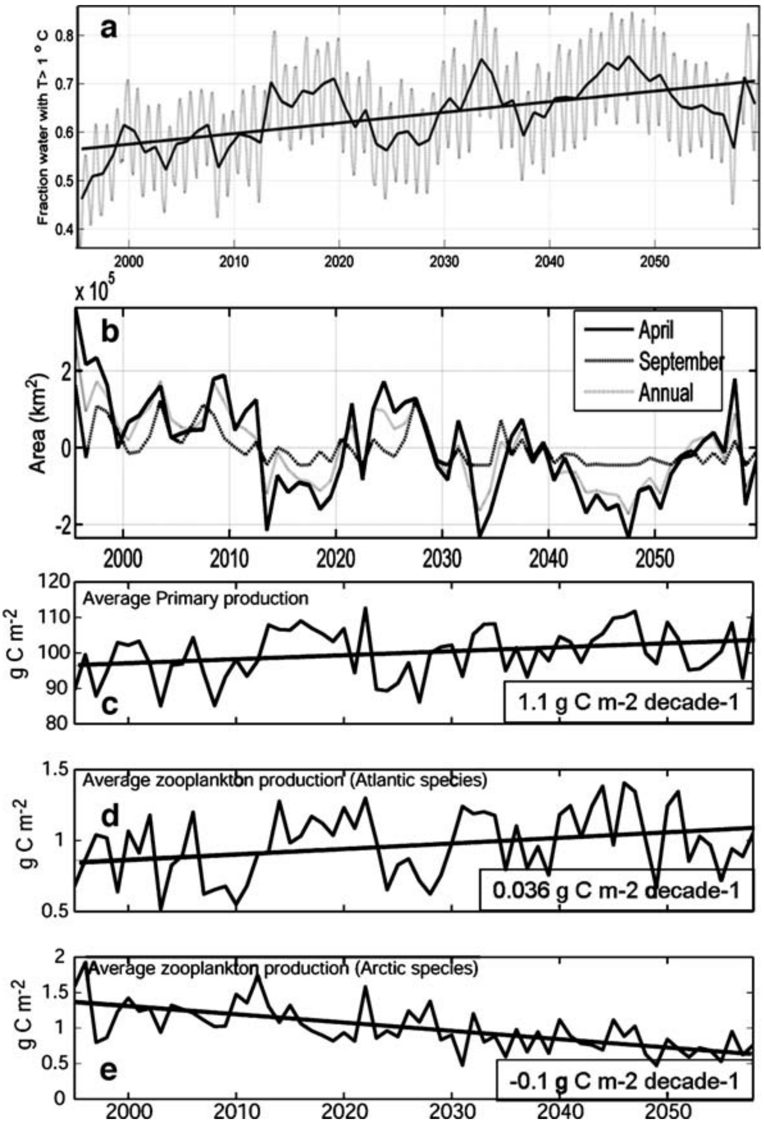

Fig. 14 Computed time series of the total fraction of water in the Barents Sea with temperatures above 10°C (**a**) as obtained by using the REMO atmospheric temperatures as boundary conditions for the time period depicted in the figure; *solid line* shows annual means, *dotted line* mean monthly values; (**b**) shows the sea ice cover anomalies (in 105 km^2) relative to long-year means for April (end of winter), September (end of summer) and the annual mean; (**c**), (**d**) and (**e**) give annual mean primary and secondary production (**d** = Atlantic zooplankton; **e** = Arctic zooplankton), respectively and their temporal trends (after Ellingsen et al. 2008)

Barents Region. The study by Dankers and Middelkoop (2008) demonstrates that under climate change conditions (based on the results of the BALANCE-RCM), runoff will increase by 25%. This influx of freshwater will have an impact on ocean circulation, temperature and salinity distribution in near-coastal waters of the Barents Sea (not quantified in present studies). Moreover, while also not explicitly treated in our models, an increase in riverine input implies a corresponding enhancement of contaminant loads to the Barents Sea with possible repercussions to marine-ecosystem health.

The hydrology of Arctic rivers is dominated by cryospheric processes. Thus, the extent, volume and duration of the snow cover have a direct bearing on hydrological processes. The study of Blyth et al. (submitted) demonstrates the impact of climate change on snow cover characteristics in our study region. The authors demonstrate that warmer temperatures and increasing precipitation (cf. Fig. 9 and Göttel et al. 2008) lead to a shorter snow season and a significant thinning of the snow cover as well as a decrease in its spatial extent in May (i.e., towards the end of the snow season) under conditions of climate change. Another important climate change impact is an increase in the number of refreezing events in 2080 compared to present conditions.

These processes not only influence the hydrology of the region, but have also important consequences for flora and fauna of the Barents Sea Region. In general, an overall decrease in snow cover is beneficial to terrestrial ecosystems and may even reinforce ecosystem integrity. However, the picture is less clear-cut than appears on first sight, e.g., with regard to reindeer husbandry (see below).

Vegetation cover characteristics (species distribution, biomass, net primary production = NPP, leaf area index = LAI) depend –aside from snow cover- on basic climatic conditions and changes with varying climate. The LPJ-GUESS model employed in BALANCE (see section 3.1 above) aims to simulate such impacts on the major plant functional types found in the Barents Region. The model projects an increase in boreal needle leaved evergreen forests (cf., Fig. 11) through extension northwards and upwards (i.e., in elevation) and an increase in biomass, NPP and LAI (Fig. 15). This expansion is paralleled by a decrease in shrublands and tundra area. In addition, climate change will lead to an earlier spring greening and an increase in the LAI. This will result in a decrease of the albedo of up to 18% in Scandinavian mountainous areas (more details, see Wolf et al. 2008a). While this result implies a clear feedback to the climate system through a modification of the regional radiation balance, the question as to whether or not the Barents Sea Region will become a net sink or source for CO_2 can presently not conclusively be answered. The shift in vegetation cover as briefly described here will clearly alter the terrestrial ecosystems in the Barents Sea Region. If this takes place at a pace which allows other components of the ecosystem to follow suit, we would not characterize this change as threatening ecosystem integrity. However, this remains an open issue which current models are incapable of answering.

Another climate change impact that clearly constitutes an adverse effect on ecosystem integrity is the possible extension of forest pests and insect outbreaks, which have been observed to result from, e.g., unusually mild winters. The LPJ-GUESS vegetation model was also utilized to investigate possible changes in insect herbivory and its impact on vegetation growth and productivity as a result of increasing temperatures (Wolf et al. 2008b). The results suggest that the predicted temperature variation in the Barents Sea Region may lead to a potential impact that will be strongest in the eastern (Russian) part of our study region. An enhanced insect damage will cause reductions in LAI, NPP, biomass and in vegetation structure. A related study by Kozlov (2008) demonstrates that the damage to northern birch forests by leaf-chewing and leaf-mining insects will at least double with the projected change in climate conditions in the Barents Sea Region.

Changes in the snow characteristics and in vegetation cover as described above will have repercussions to reindeer husbandry. As mentioned above, while generally favourable, changing snow conditions, particularly a higher frequency of refreezing events will cause problems for winter feeding. The decrease in tundra area as a result of climate induced

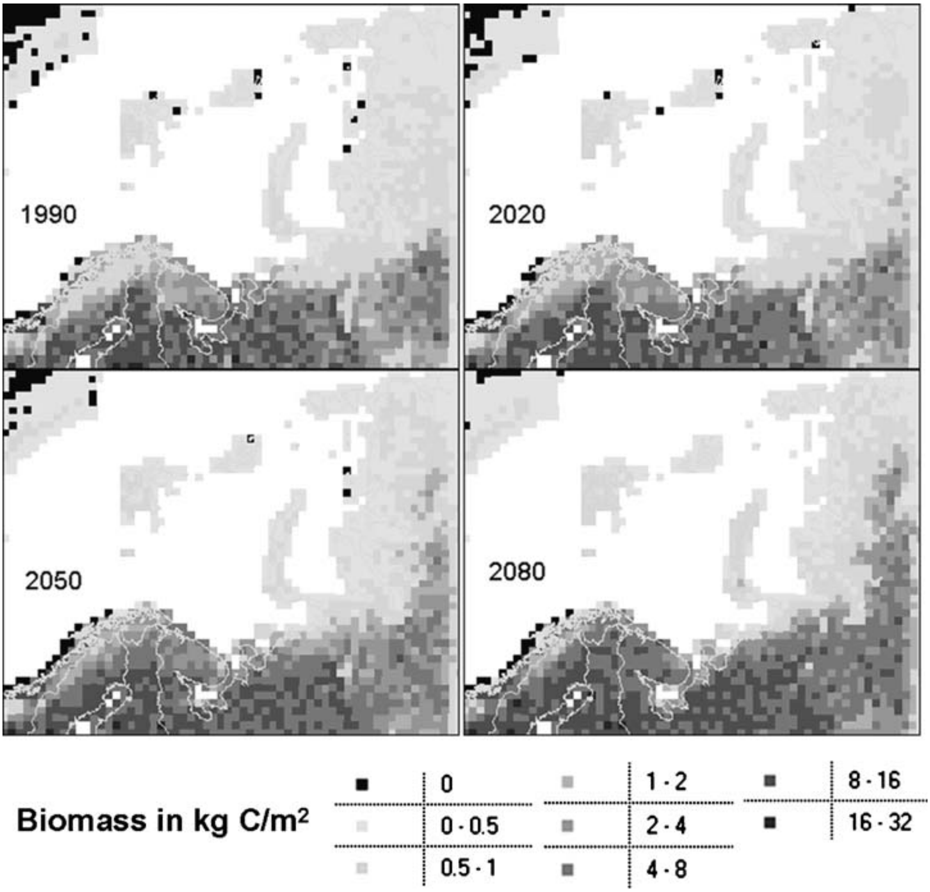

Fig. 15 Projected mean annual biomass in kg Carbon per square meter from a dynamic vegetation model (LPJ-GUESS) driven by a climate scenario derived from the BALANCE-RCM for four different times; please note the gradual northward expansion of higher biomasses (4 to 16 kgC/m^2) as time progresses (Wolf, pers. comm.)

vegetation changes also reduces the availability of pasture for reindeer and thus may lead to declining population numbers. However, the effects of climate change on vegetation cover and thus on reindeer husbandry will be unevenly distributed throughout the Barents Sea Region (see Rees et al. 2008). While the western part of the Barents Region will see a significant decrease in pasture area, the eastern (Russian) parts will experience a shallower decline if not a slight increase in grazing area. Therefore our results suggest a decrease by as much as 60% in reindeer numbers in Norway and a slight increase of about 10% in Russia.

A major measure of ecosystem integrity is the diversity of habitable species in a given region. Conversely, a change in habitats such as described above with regard to vegetation changes will have consequences for biodiversity and species distribution. Thus, a decrease in tundra area will threaten the existence and survival of tundra species. In a study in the framework of BALANCE, 14 indicator species of ground nesting birds and their likely fate under conditions of climate change have been investigated (Zöckler et al. 2008). Except for two species, the area of occupancy for the birds will decrease with changing climate and shifts in vegetation zones as derived from the LPJ-GUESS model (see above). While the model projects that 14% of the tundra area will be lost due to vegetation changes, about 19% of the overall area may become new tundra. However, it is questionable, if this new tundra will serve as a substitute for the lost tundra area for the bird species considered. Thus, the net impact of a change in climatic conditions for the indicator bird species considered will be a loss in habitat and thus a decline in population numbers in the Barents Sea Region.

4.2 Sustainable utilization of natural resources

The impacts on marine and terrestrial ecosystems caused by climate change described above will have implications for the utilization of these ecosystems as natural resources. Thus, economic sectors directly dependent on renewable natural resources will be similarly impacted by climate change. A decrease in the availability of these resources as a consequence of climate change may lead to the over-exploitation of particular components to the extent that sustainability might be jeopardized. While not explicitly considered in BALANCE, we did look at the exploitation of fish, timber and reindeer as major economic activities in the Barents Sea Region in light of sustainability.

With regard to marine resources, this is a difficult undertaking. Figure 16 represents historic stock sizes for capelin, cod and herring (1st and 2nd year class) for the Barents Sea.

As can be seen, while capelin and herring show significant variations, cod stocks seem to be relatively stable over the period covered. On closer look, though there is a correlation between capelin and its main consumer, cod as well as between herring and capelin from 1983 onwards. However, this distribution does not only reflect a natural development, e.g., determined by zooplankton availability, but is likely significantly influenced by human exploitation. This might be particularly relevant for herring, which seems to almost entirely disappear for certain periods in the record. Thus, if we consider the changes projected in major stock characteristics as impacted by climate change and as briefly described above, it is difficult to judge if a sustainable exploitation might be achievable without strict limitations on catches through, e.g., fishing quota. A minimal requirement to ensure sustainable harvests would be a continued close monitoring of fish stock sizes in order to adjust quota or impose moratoria on particular species.

With regard to terrestrial resources, a sustainable utilisation of timber at present levels may very well be possible given the projected increase in biomass in general and in boreal

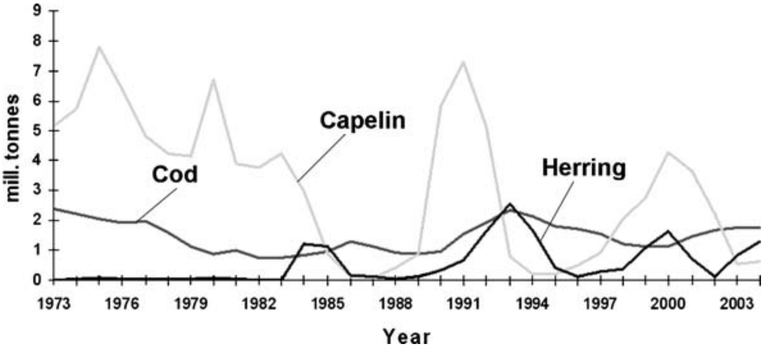

Fig. 16 Stock sizes of major fish species in the Barents Sea for a 30-year period based on sampling surveys (Dalpadado, pers. comm.)

needle leaved evergreen forests in particular (see above). However, the described enhanced damage by insects as a consequence of climate change may jeopardize such a prospect. Moreover, in a study by Lundmark et al. (2008), it is concluded that an economically viable exploitation of forest resources might be much more severely influenced by single extreme (storm) events than by a gradual change in climate. Such a storm event may have severe consequences for the development of the local to regional forestry industry and may also result in the temporal over-exploitation of the remaining resources in order to satisfy the demand for timber.

Forestry and reindeer husbandry often compete for the same land area. Thus, conflicts have arisen in the past between forest owners and reindeer herders when reindeer have entered forests to feed on lichen or on young tress plants. Conversely, the exploitation of forests through modern production technologies requires infrastructures (e.g., paved forests roads) that disturb reindeer. With a shift in vegetation and a decrease in tundra area, an increased pressure on forests as possible feeding grounds for reindeer may arise. This will also contribute to an unsustainable development, which can also only be avoided if the combined impacts of climate change and reindeer husbandry on forests is closely monitored and/or regulated.

As described above, reindeer husbandry will be differently affected by climate change depending on the geographical distribution of climate-induced vegetation shifts. Thus, particularly in the western parts of the Barents Sea Region, sustainable reindeer herding will only be possible, if herd sizes are being reduced and/or new ways of herding practices are being introduced (e.g., winter feeding, fencing, etc.; for more details see Rees et al. 2008). However, the latter have to be regarded unsustainable in a larger context in most instances.

4.3 The importance of climate change for the development of the Barents Sea Region

In our project, we addressed the question as to the overall importance of climate change for the development of the countries in the Barents Region. This was primarily pursued in the context of socio-economic studies and the work with the stakeholders. When considering the impacts of climate change on the Norwegian fishery industry, it was concluded that climate change is likely to be of less importance compared to political and economical drivers. In particular, fishing quota or the competition of other (non-European) fishing nations are considered more important for the prosperity and “health” of the fishing industry. Adapting to these pressures is seen as much more demanding as compared to adaptation measures needed to reduce climate change impacts (for more details, see Eide 2008).

In the case of forestry, the availability of technology and infrastructure, global market forces and government regulations and limitations impose stronger constraints on the industry than anticipated for possible climate change impacts. Moreover, as mentioned above, climate change is only seen as a major determinant of economical development, if it leads to increased frequencies of extreme events, which are considered to seriously reduce available resources.

Reindeer herders are probably the most directly vulnerable in terms of climate change impacts. The availability of food, adequate and sufficient grazing areas, the presence of ice layers or enhanced insect harassment as a consequence of extremely warm summers are all factors that are difficult to adjust to. However, our studies show that traditional adaptation strategies are still pursued and have resulted in relatively modest vulnerabilities to environmental factors. However, in combination with adverse socio-economic conditions climate change may lead to negative impacts that pose a more severe challenge to reindeer herders. As was shown (Rees et al. 2008), subsidies are most important factors in determining the fate of reindeer herders, clearly/apparently overriding any impacts that climate change may cause. In accord with the spatial distribution of vegetation cover changes and other biophysical characteristics (e.g., snow cover, temperature and precipitation distribution), the environmental pressure on reindeer herders is considered negative in Norway and Sweden, neutral in Finland and slightly positive in Russia. Conversely, adaptive capacity by means of advanced technology and methods varies also greatly and is higher in the Fennoscandian countries compared to Russia.

As already described, stakeholders, when asked about their view on climate change they largely consider it but one (mostly less important) factor determining their future. In many cases and based on the already evident changes and impacts, stakeholders have developed strategies that “factor-in” climate change in a whole suite of other considerations that often appear to be more decisive (Keskitalo 2008). Thus, while not denying the existence of climate change and its possible impacts, stakeholders consider them as part of a larger, more interwoven net of drivers that they have to adjust or to adapt to in order to maintain their livelihood.

5 Conclusions

Climate change in the Arctic and in the European North is by now an undeniable fact. In order to understand how the impacts of climate change affect environmental integrity and the well-being of local residents, integrated assessments on a regional to sub-regional scale are required. The EU-funded BALANCE project (Global Change Vulnerabilities in the Barents Region: Linking Arctic Natural Resources, Climate Change and Economies) was an attempt to achieve such an assessment for the northern parts of Fennoscandia, the Kola Peninsula and the Archangelsk Oblast (Russia). The major methodologies employed were individual impact models driven by a dedicated regional climate model. The results of the impact models were compared to a development without climate change (“business as usual”) in order to derive the impacts for specific components of the Barents System. Integration was pursued through various means, including vertical integration along impact chains, an IAM-RC and horizontal integration across major compartments of the BSS (Fig. 5). A major component of the project was an attempt to actively involve stakeholders in the assessment of present and future climate change impacts and the conceptualization of possible adaptation strategies.

As a result of the horizontal integration, a few overarching questions have been addressed. When considering climate change impacts on environmental integrity, each component of the Barents Sea Region is affected differently. Marine ecosystems, while clearly reacting to climate change (e.g., in terms of changing sea ice cover), seem less vulnerable. However, changes in migration patterns and spawning characteristics will have consequences for stock sizes and stock compositions. Exploiting these stocks sustainable will require a close monitoring of stock development and the possible introduction of fishing quota.

Terrestrial processes will have a bearing on marine ecosystem only in terms of riverine discharge, which is likely to increase under climate change conditions. The possible resultant changes in ocean circulation and water characteristics (including contaminant loads) have not been explicitly addressed.

Climate change will lead to major impacts on snow cover characteristics and on terrestrial vegetation. Geographical shifts in vegetation zones will clearly affect ecosystem integrity, particularly so, if the affected ecosystem is unable to cope with the pace of the changes in particular plant or tree species. Changes in vegetation cover will have repercussions for ecosystem services, particularly for forestry and reindeer husbandry. However, climate change will be but one factor affecting these sectors and has to be seen integratively with other drivers.

Both, economical investigations and stakeholder interviews seem to suggest that climate change may not play a decisive role in shaping the future of the Barents Region. However, this conclusion is based on the assumption that we already have sufficient knowledge about the overall functioning of the system and that the major dependencies and interrelationships will not significantly change in the future. This, though are fairly risky assumptions, whose validity can presently not be assessed. Thus, we therefore maintain that climate change adds a layer of uncertainty to an already highly uncertain future that cannot be ignored by anybody interested in the well being of the region and its residents.

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