Chapter 12
Threat Mapping

An Introduction

When applying a strategy to a site, threat mapping may allow us to provide spatial information related to factors and events which can affect the environmental components of ecological and conservation concern (targets). In such a way, an evaluation of different aspects of the events is made possible also with relation to local environmental values (for examples, see Pressey et al. 2007; Wildlife Conservation Society—Didier et al. 2008; Brown and Baker 2009).

Maps used to localize threats can provide information about event localization, distribution, extent, form, contiguity, dispersion, connectivity,[1] assigning specific magnitude and severity scores (or scores related to other regime attributes) to particular patches. Such information, derived from spatial data, can be combined with the information collected from the data related to biological diversity (presence, distribution, composition, density, cover, richness, or diversity of specific targets such as those constituted by species or habitat types of conservation concern). The procedure can allow us to understand which areas are more sensitive, vulnerable, critical, and in need of priority interventions. For example, they can be sites where the highest severity and magnitude values are accompanied by the highest values of target density, cover, and diversity (Wilson et al. 2005). Mapping information about threats can also enable us to identify the areas of high conservation priority (defined as *problem areas*, Latour and Reiling 1994; Reyers 2004).

Not all threats can be represented on a map in the same way. However, a precise representation can be given of those characterized by unmovable structures, spread

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[1]A great deal of spatial parameters of landscape patches (other than those which have been mentioned so far) can be calculated by different softwares (e.g., FRAGSTAT).

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on defined surfaces with a high level of detail, and whose regime is known with little uncertainty (such as linear and point-shaped infrastructures, forest cuts, urbanization, and in general, the physical changes of soil usage belonging to the IUCN category known as *habitat conversion*).[2] Other events are more difficult to be mapped, such as those characterized by dynamic, inconstant, uncertain, and unpredictable distribution or other shifting regime characteristics (among them: alien species, or dynamic processes such as water stress or atmospheric pollution).

The modalities which can be utilized for threat mapping depend on the project team's expertise and the reference scale of the project. To realize a thematic map showing the threats to a site, the following steps may be taken into consideration:

(a) selection of the more appropriate basic information data set, taking into consideration spatial scale and grain of both threat events and conservation targets;
(b) definition of format modalities, data representation and informative units (whether raster or vector; using polygons, square grids, gradients, or points as input to subsequent interpolation)[3];
(c) identification of the threats present in the site and relevant to the project, also taking into consideration the driving forces.[4] To create a map, it may be necessary to consider all the identified threats, in order to select only those represented by a consistent data set which may allow us to obtain reliable patterns to be represented in an informative layer;
(d) making a multilayer map which shows whether each threat is present or absent (first informative level) or the values of certain attributes/variables (e.g., severity; the attributes are properly represented by different colors and symbols according to the score assigned); the values assigned to the attributes

[2]Wilson et al. (2005) have identified the threat/driving forces which can be more easily represented on a map, namely: urbanization, infrastructures, mining, invasion of allochtonous species, agriculture, grazing, deforestation/forest management, and in some cases, alteration of natural disturbance regime and climatic changes.

[3]The use of the most common systems of territory analysis and representation such as the GIS (Geographic Information System) obviously need to be utilized. Representation modalities may vary greatly but they must satisfy the need of clarity, reliability, readability. For example, impact buffer areas can be reported around sites where stress sources are located (e.g. in the areas adjacent to infrastructures; buffer areas might be defined as follows: 100 % impact/severity within 5 m; 50 % impact within 25 m etc.). Buffer extent and gradation differ among threats and as a function of the sensitive targets). A priority in this sector, is the definition of conventions on buffer extent for specific threats in given contexts and geographic areas.

[4]In general, the information related to individual direct threats are relatively easier to indicate on a map than those concerning the driving forces.

related to each threat (or to all threats) can be stratified in order to obtain a total value for each area[5] (e.g., sum of the magnitude values);

(e) analysis of the data related to the threats; the data are then compared to the environmental values of importance to the site (for example, species or habitat types) in terms of presence, density, and other quantitative parameters considered in their spatial dimension in order to indentify critical or conflict areas requiring more urgent interventions.

Data can be mapped which are directly related to certain threat events or it can be decided to use indirect information through the use of proxy indicators.[6] They usually need to be employed when it is difficult to gather direct information on the threats. For example, should the necessity arise to indicate the areas where agricultural vehicles usually travel or where chemical fertilizers are used, the cultivated areas can be identified on the map assuming that their distribution indicates the distribution of the threats to them (passing vehicles and chemical fertilizers). The information about proxy indicators is more easily gathered (it can be obtained, for example, by utilizing socioeconomic indicators indicating a predisposition to the risk; Theobald 2003). However, they provide less accurate, approximate information which is also theoretically different (based on patterns rather than on processes; Burton 2007). A proxy indicator can represent different threats (see previous example).

The data utilized for threat mapping must be solid and representative of an appropriate temporal scale (for example, 1–5 years, depending on the perturbation type) in order to be reliable and to provide a suitable explanation of the characteristics of the phenomenon under observation. This is particularly important given the dynamicity and unpredictability of many threat events.

Noteworthy, many patterns and processes continuously change in space and time, whereas mapping modalities may require that some information be represented in a discrete way (such as in the so-called deterministic zoning approach, widely utilized in territory planning; Keith 2009).

Practitioners should always be aware that a difference also exists between the information mapped and the real world. In most cases, the information necessary to map the threats are unavailable at the scale of the site or of the whole area under observation. Thus, very often, the information reported on the map derives from extrapolation/interpolation processes carried out on original point-shaped data. Hence, knowing how to carefully perform data conversion from one scale to another, is very important. In general, data related to a fine-grained scale can be

[5]The measurement can be based on different scales, namely: nominal scale, it allows us to indicate only the presence or absence of a given event in an area; ordinal scale, which subdivides categories into ranks (high, intermediate, low) in relation to certain regime attributes; interval scale, it indicates regular measurements of a given parameter without referring to an absolute zero (e.g., temperature); ratio scale, indicating the interval values of a variable which starts from an absolute zero (e.g., surface, length).

[6]A proxy (or indirect) indicator is a variable through which a phenomenon is approximated or represented in the absence of a direct measure.

converted to lower resolution scales, but the opposite would be incorrect since it might entail a loss of accuracy. A GIS expert or a data analyst should in such cases work alongside the project team.

Finally, maps allow us to compare past, present and future situations (ascertained, potential, or predicted by different scenarios) and diachronic maps can be plotted, if necessary. The latter provide information about the shifts of spatial threat patterns over time. For a more in-depth analysis, see Salafsky et al. (2003).[7]

Plant ecologists have developed many approaches to detect disturbances on vegetation and many examples are available (see Pedrotti et al. 1979, 1996; Petriccione and Claroni 1996; review in Pedrotti 2013a, b).

Plant-Based Mapping as a Tool for Revealing Natural Disturbance and Anthropogenic Threats *(Franco Pedrotti)*

The bioindicator role of plants in assessing the anthropogenic impact: Due to their morphological and functional characteristics, plants show their conservation or alteration status in every moment. They also reveal us how strongly they are affected by anthropic activities. Therefore, plants can be considered general biological indicators of the environment where they develop.

Their role as bioindicators derives from the fact that plants have more or less stringent needs with respect to the environmental conditions. Therefore, their presence in a certain place informs us about the natural characteristics of the physicochemical and biological environment as well as about its possible alterations. This is valid both for species and communities.

For species, it was Ellenberg (1974) among the first to propose the bioindicator values for the vascular plants of a large territory, i.e., central Europe. Subsequently, other authors, for example Pignatti (2005) in Italy, have given their contribution for other geographical areas.

Géhu (2013) points out that plant communities when characterized by strict floristic and synecological homogeneity are excellent bioindicators, or more precisely, biocenotic indicators. Frequently the information which can be gathered from them is more accurate than that obtained from individual species. This has been widely demonstrated by the phytosociological research on vegetation carried out in every country in the world, starting from the last century with the work by Braun-Blanquet and Tüxen to the present day. For all these reasons, the "botanical" approach is particularly useful in environmental assessment, including the detection of natural and human-induced disturbances, and in the construction of the related maps.

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[7]See also the contribution of the Italian Society of Ecology about the cartographic presentation of environmental components and pressures (Rossi 2001), and, in particular, the contribution concerning the representation of the anthropic pressures for the Carta della Natura mapping project.

What is mapping good for?: From a botanical point of view, disturbance can be said to affect species, vegetation (constituted by vegetal associations) and vegetated landscape. Indeed, the levels of knowledge and therefore the cartographic integration related to plants are much more articulated and can be listed as follows (Pedrotti 2004; 2013a, b):

> *I Phytoindividual and II Plant population (species); III Synusiae; IV. Phytocoenoses and V Ecotopes (teselas, i.e., vegetation); VI. Catenas (vegetated landscapes); VII lower phytogeografic units (regional); VIII – higher or general phytogeographic units (phytogeographic subdivisions).*

Many authors such as Zonneveld (1974), de Laubenfels (1975), Ozenda (1982), Küchler and Zonneveld (1988), Faliński (1990–1991, 1999) and Pignatti et al. (2001) suggested other classifications of knowledge levels which were less numerous than those listed here, although related to a group of common levels. This is because in some of those proposals, references to the levels of teselas, series and geoseries were not included. Indeed, synphytosociology and geosynphytosociology allow us to increase knowledge opportunities and to obtain a more detailed and precise subdivision of the integration levels.

As far as the assessment of anthropic disturbance and cartography are concerned, knowledge levels acquire different meanings according to the different problems to deal with. Levels I and II (phytoindividual and phytopopulation) reflect plant distribution and abundance, and respectively, species distribution (chorology); levels III and IV (synusiae and phytocoenoses) refer to the conservation status of plant communities, synchorology, and beta-diversity; level V (tesela) refers to the phytocoenoses when considered in relation to their spatial distribution (vegetation series); level VI (catena) refers to the vegetated landscape (gamma-diversity); level VII and VIII (phytogeographic units of different ranks) refer to the phytogeographical subdivisions of the territory. Level VII and VIII so far have not been taken into consideration for disturbance assessment, since they represent very large units which, in turn, include series and geoseries. The latter units are appropriately used for reference.

The knowledge levels listed here can be used in the assessment according to the disturbance type; an appropriate cartographic representation can be produced using one (or more) of those levels, as will be explained later in the text.

Mapping threatened plants at two scales—population and distribution area: In nature species exist under the form of individuals, elementary organisms assembled into populations that live in the same place, occupy the same biotope and exchange their genes in the reproductive processes (Canullo and Falińska 2003). As far as individuals are concerned, it is possible to build population and chorological maps of the species; in the first case individual organisms and the populations they constitute are highlighted; in the second, the partial or complete range of a given species is pointed out (Fig. 12.1).

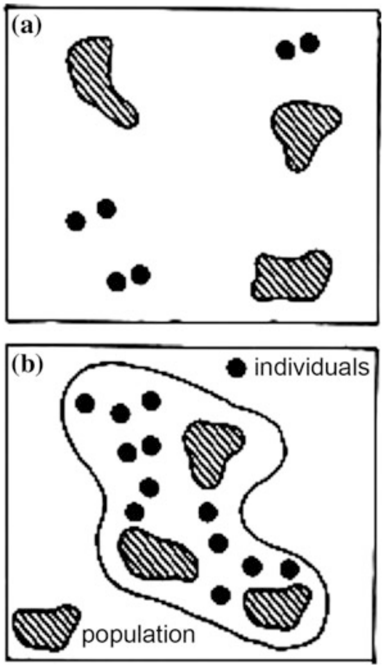

Fig. 12.1 **a** Example of distribution map of some species' individuals (indicated by *symbols*) and populations (indicated by a *cartographic unit*); **b** Example of a species distribution map, which includes individuals and populations (from Cristea et al. 2015)

Human-induced disturbance causes the disappearance of individual organisms and populations from the stations in which their presence has been historically documented, that is locations where the species has been signaled in relatively recent times. This may be due to different causes, like, for example, harvesting for human needs or a shift in the environmental conditions.

Disturbance effects can be mapped indirectly by reconstructing, based on literature data and herbarium samples, the chorological map of the species under study and by comparing it to a current chorological map, on which the missing stations will not be shown (Fig. 12.2). If characterized by a great extent and prolonged over time, disturbance can lead to a more or less marked contraction of a species' range, as it has happened for many species all over the world. For example, Nebrodi fir on Sicily mountains has undergone a marked range contraction and today it is reduced to 27 individuals all localized in the Vallone Madonna degli Angeli on Monte Scalone slopes.

Many species, particularly those which have become rare because of phytogeographical and ecological reasons (due to rarity of certain types of environments), are subjected to a progressive reduction, due to different anthropogenic reasons, like urbanization, pollution and water eutrophication. Among the many instances, *Carex lasiocarpa*, in the Trentino region, is a case in point. This species, in some lakes, forms floating meadows and is known only in not more than ten stations, being absent at least from two locations, namely Serraia Lake and Laghestel, on the Piné

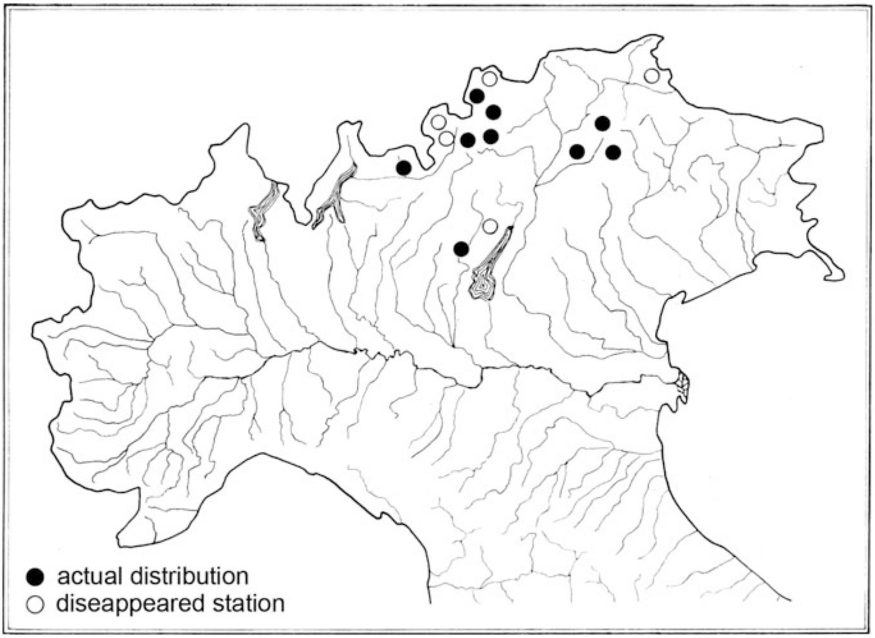

Fig. 12.2 Italian distribution of *Paludella squarrosa* (Hedw.) Briq. (from Cortini Pedrotti 1979, modified)

plateau (in the Trentino region), because of water pollution and the subsequent disappearance of the floating meadows which hosted it.

In some cases the number of disappeared species from a study area, for example a lake, has been calculated. In the Caldonazzo lake, the Levico lake and the Loppio lake (all located in the Trentino region) the percentage of disappeared species are: 22.2, 12.5 and 13.2 %, respectively. In the Trasimeno Lake (in the Umbria region) a great percentage of the species, 15.6 %, has also disappeared (personal survey). Moreover, some rare species have disappeared in the Colfiorito swamp (Umbria region). Among them, *Eriophorum latifolium*, which thrived in the only strip of peat bog present in the whole Umbria region, an area of a few square meters, has disappeared because of the peat extraction and the excavation of drainage channels. Similar considerations might be made for a number of other Italian and European locations.

Carrying out research on phytopopulations is a rather difficult task, since many of them usually thrive in the same phytocoenosis. Making relevé is also very demanding, as shown by the study carried out by Falińska (2003) in the Bialowieza (Poland) meadows. In order to assess possible changes, such as reforestation subsequent to the abandonment of mowing procedures (Fig. 12.3), the latter research has been repeated over the course of different years. In order to monitor the changes occurring at the phytocoenosis level, permanent monitoring plots are employed,

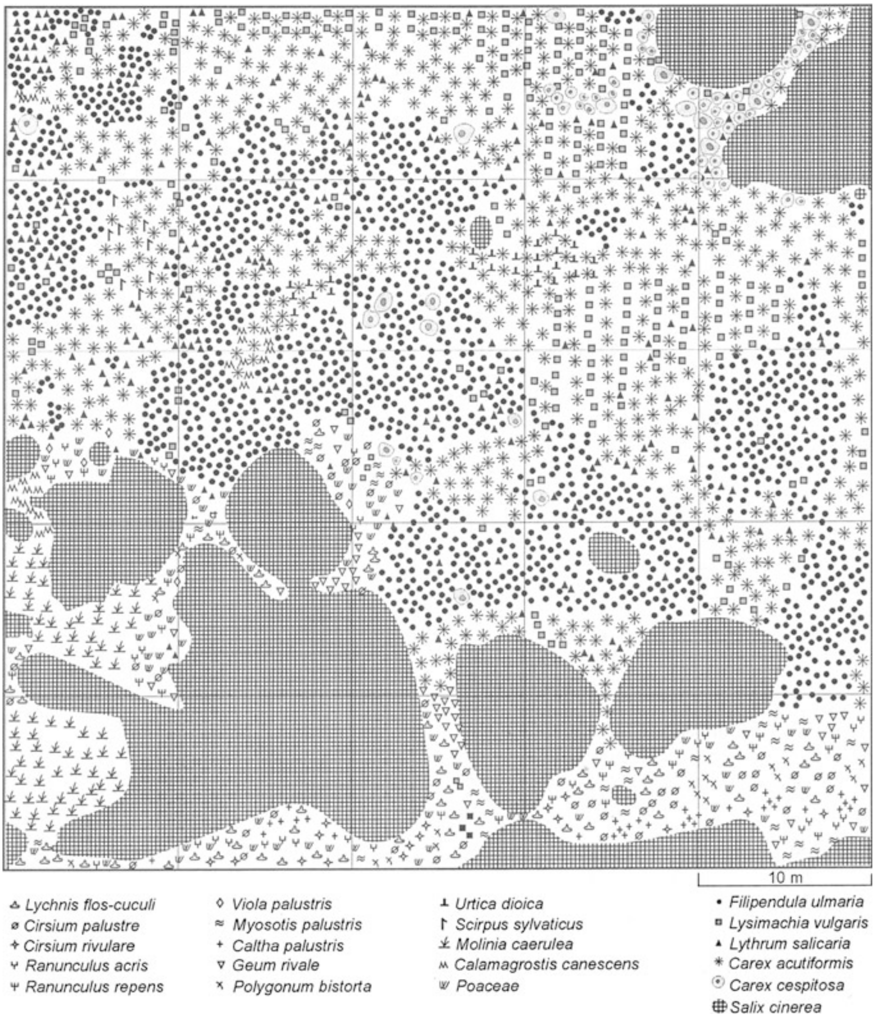

Fig. 12.3 Map of the phytoindividuals of 25 perennial herbaceous species in a meadow area of 50 × 50 m at Remski, Bialowieza, Poland. Each symbol is related to a single phytoindividual; the phytoindividuals of *Salix cinerea*, a shrub species, have been mapped with a continuous surface (from Falińska 2003)

such as those of the CONECOFOR (national program for forest ecosystem control) Italian network (Canullo et al. 2012).

Mapping threatened plant communities: A plant community is constituted by a more or less homogeneous and structured group of plants with well-determined range and environment (Géhu 2013). It is the equivalent of a plant association. The latter, in the wild, is formed by phytocoenoses, i.e., more or less similar vegetation units distributed in suitable locations.

The assessment of a disturbance affecting plant communities and the production of the related maps are carried out using the phytosociological maps on which plant associations are represented. A phytosociological map can also be considered as a beta-diversity map. To calculate beta-diversity, however, only natural and semi-natural associations should always be considered, with the exclusion of synanthopic associations, formed by ruderal and nitrophilous species, many of which are neophytes. In the case of the Levitico lake (in the Trentino region), 5 associations are present (among which the *Thelypteridi-Alnetum glutinosae* marshy forest), all very rare in that region, whereas in a nearby area open to tourism, 10 associations are present, all induced by human presence. Therefore, it turns out that the protected biotope with a high degree of naturalness is characterized by a lower value of beta-diversity when compared to the contiguous area, with a lower degree of naturalness. The same result has been obtained by a research carried out in the Bialowieza forest (Poland) where a vegetation map has been constructed in a sector of 3 × 2 km. One half of it is included in the national park which dates back to 1921 and at that time it was already a virgin forest. The other half is outside the national park and is subjected to economical cutting procedures, with subsequent formation of more or less extended clearings. Potential vegetation is the same in the two sectors and is represented by the *Tilio-Carpinetum* forest, but because of anthropic disturbance, the actual vegetation is different. In fact, within the clearings, three associations have developed which are not phytogeographically relevant since they are diffused all over Europe. Therefore, the biodiversity characterizing the sector included into the park can be described as "negative" because it is of no use from a botanical/biological point of view (Pedrotti 2011 and 2013a, b). It turns out, then, that human presence affects secondary biodiversity because it contributes to its maintenance. On the contrary, to preserve primary biodiversity, human-induced disturbance should be eliminated, at least in protected areas.

Another problem to deal with is the assessment of the phytocoenosis (vegetation) conservation status. The most useful method is based on the assessment of the dynamic tendencies occurring in the phytocoenoses at the time when they are sampled in the relevés; the maps of the dynamic tendencies of the vegetation (according to Faliński and Pedrotti 1990) represent the processes related to the dynamics acting on the phytocoenoses, which is due to natural causes or to the human action on them. Therefore, it can be said that they are related to the dynamic state of the vegetation.

The dynamic processes include: fluctuation, primary succession, secondary succession, degeneration, regeneration, regression. *Fluctuation* is a reversible dynamic process of relatively short duration, but long-lasting; it consists of all the small, continuous changes that concern the components of a given phytocoenosis but do not change fundamentally the type of phytocoenosis which remains the same; these changes take place inside the phytocoenosis and result in a dynamic equilibrium. Examples of such changes include: the gradual exchange of components, the creation of small glades in a forest due to the fall of older trees which are then substituted by younger ones, etc. In Italy few are the forests concerned by the fluctuation process. A classic example is the Sassofratino forest, constituted by *Abies alba* and *Fagus sylvatica*. Fluctuation also concerns primary meadows, as it can be observed on all the mountainous chains above tree and shrub line. *Degeneration* is an ecological process inside phytocoenoses, which entails modifications in structure and floristic composition but also without changing the type of phytocoenosis. In the first case and in forest phytocoenoses, the tree canopy is thinned out after tree cutting and the reduction of high forest to coppice forest. In the second case, the herbaceous species of the understorey may disappear and foreign, ruderal, nitrophilous species, neophytes, etc. (synanthropic species) may be introduced. A classic example of forests affected by the process of degeneration by structure modification are coppiced woods, particularly those constituted by ashes (*Fraxinus ornus*) and European hop hornbeams (*Ostrya carpinifolia*), both located on the Alps and the Apennines. At the present time, numerous associations, such as the forests of *Abies alba* in the Trentino region (Gafta 1995), are affected by a degeneration process through modification of the herbaceous species present in the understorey. A progressive invasion of black locust (*Robinia pseudoacacia*) is occurring in all the hornbeam (*Carpinus betulus*) woods of Valsugana (in the Trentino region) because of anthropic causes. In many instances, *Robinia pseudoacacia* has almost completely replaced the original species of the tree layer.

Regeneration is an opposite process with respect to degeneration. It entails the reconstitution of the original situation for internal processes of recovery after a disturbance; for example, can be observed in coppiced woodlands, which are no longer subjected to the periodic cycles of cuttings, or in high forests where human activities (for example grazing in the woods, so common on the Apennines) have ceased.

During *succession*, plant associations are reconstructed from the beginning in a multi-year cycle, which lasts until the phytocoenosis reaches its full maturity, i.e., its stability, characterizing the climax stage. Two types of successions can be identified, namely primary and secondary successions. In primary successions, vegetation develops on substrates devoid of organic substances such as alluvial deposits, volcanic lava, rock debris, etc. Secondary succession occurs in places where soil contains at least organic matter, such as in abandoned fields left uncultivated and in secondary grasslands no longer grazed and mowed. Therefore, secondary succession allows forest restoring in areas where, in the past, forest vegetation was eliminated.

Successions are characterized by the progressive passage from an association to another through the succession stages, such as, for example, in the case of the shrub layer which invades grasslands and lays the ground for the developing of the tree layer and the forest. An example of secondary succession is given at Fig. 12.19: a meteorological extreme event. It has resulted in the destruction of the *Luzulo Piceetum* forest and the formation of a vast clearing, immediately affected by the formation of secondary succession with *Rubetum idaei* and *Salicetum capreae*; the

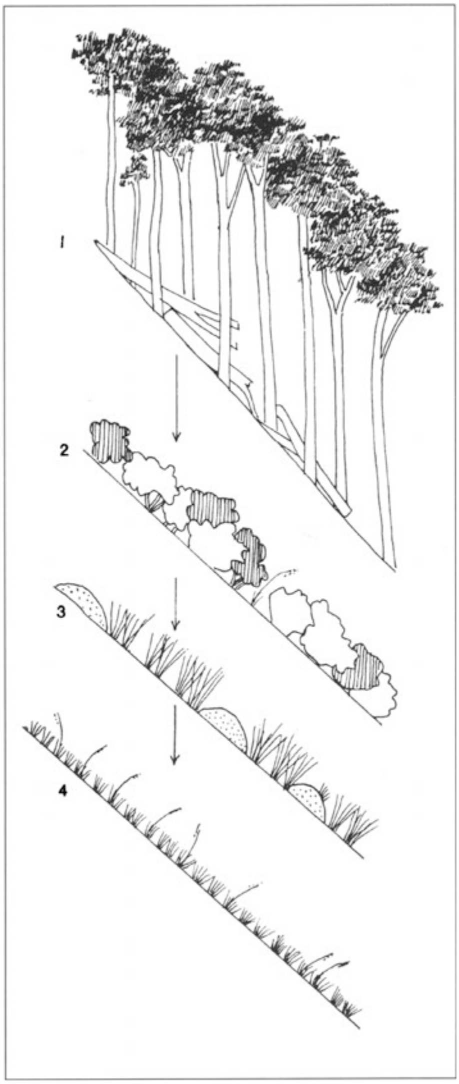

Fig. 12.4 Dynamic processes in the forests of *Nothofagus pumilio*, Patagonia, Argentina; *1* fluctuation in forest of *Mayteno-Nothofagetum pumilionis*; *2* forest regression due to wood cutting, grazing and fire-matorral of *Elymo-Chiliotrichetum*; *3* pajonal of *Stipo-Mulinetum spinosi*; *4* grassland of *Triseto-Poëtum pratensis* (from Roig et al. 1985)

Salicetum capreae tends to evolve, within a few years, to the forest of *Luzulo-Piceetum.*

Regression is a process of gradual simplification of plant associations under aggressive action of external factors and may proceed to complete substitution by other plant associations (Fig. 12.4); in extreme cases it may lead to their complete destruction leaving soil with a very sparse plant cover or no plants at all. In a location called Viotte del Monde Bondone (in the Trentino region), grasslands are in the fluctuation stage and therefore are well preserved. However, there are

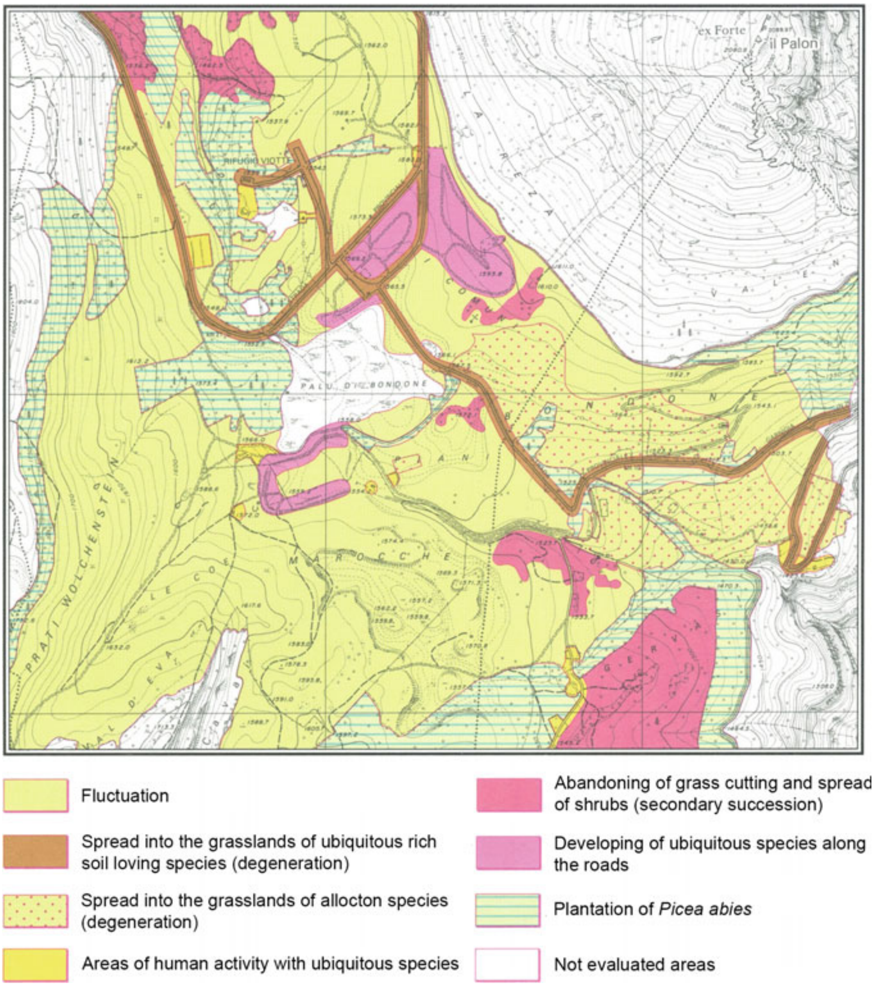

Fig. 12.5 Dynamic processes in the meadows of Viotte del Monte Bondone, Trentino, Northern Italy (from Pedrotti 1996)

worrying signs for their status which is worsening because of various reasons, all indicated in the maps (Fig. 12.5).

When a phytocoenosis is interested by the processes of fluctuation and primary succession it means that it is affected by disturbance directional actions. In the other cases (degeneration, regeneration, secondary succession, regression), phyto-coenoses are affected by more or less serious and detectable processes.

Human-induced disturbance to vegetation can be mapped through the production of dynamic tendency maps; these maps coincide to phytosociological maps to which indications of ongoing dynamic tendencies in the different chartographic units, through different abbreviations and colors, are added.

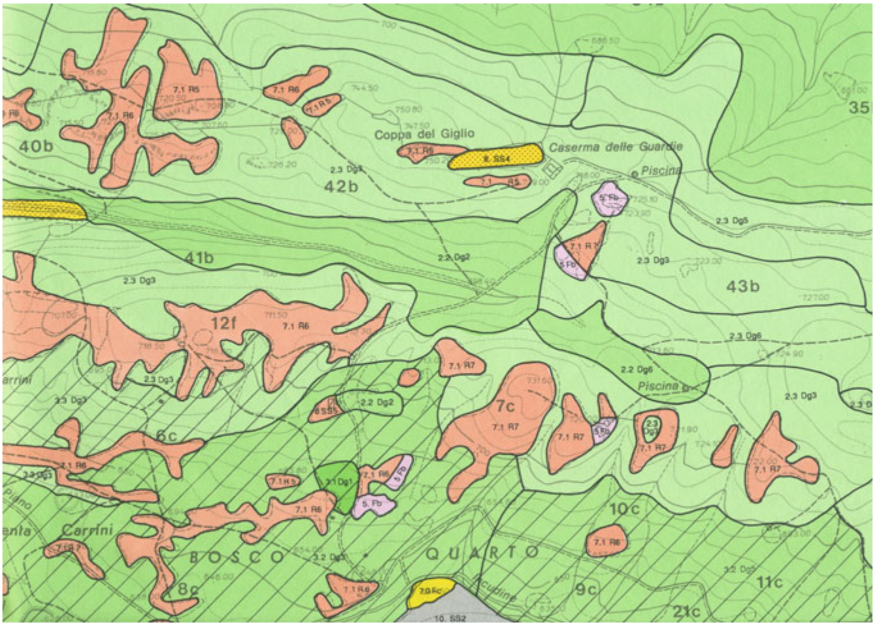

Fig. 12.6 A sector of the vegetation map of the "Bosco Quarto", Gargano, Apulia, Southern Italy. *Green colors* indicates forest associations, among which the *Doronico-Carpinetum betuli*; in the valley bottom, forest is continuous whereas on the slopes is interrupted by numerous clearings (in *red*) mainly due to overgrazing (from Faliński and Pedrotti 1990)

A classic example of a dynamic tendency map concerns the Bialowieza forest in Poland (Faliński 1986). Using the same criteria, maps concerning the Bosco Quarto forest (Apulia) and the Mainarde (Molise) have been made by Faliński and Pedrotti (1990) and Canullo and Pedrotti (1993). These mapping approach has already been employed successfully by botanists from various countries, even though nomenclature may differ in some instances and methodology (Emborg et al. 2000; Giurgiu et al. 2001; Velasquez et al. 2003; Bioret and Gourmellon 2004; Mucina 2009; Ziaco et al. 2012).

Other aspects concerning forests and other vegetation types, for example the herbaceous one, are continuity and progressive elimination, which may lead to the complete disappearance of the vegetation cover. In Fig. 12.6, a sector of the Bosco Quarto forest on the Gargano promontory is showed; such a forest is characterized by some well preserved and continuous zones partly affected by the fluctuation process (in the valley bottom) and does not show detectable signs of human-induced disturbance; in a large slope area, however, many clearings suitable for grazing have been made.

Fragmentation consists in the loss of vegetation continuity and in its reduction to smaller and more distant strips unconnected from one another. In a few instances, such as the forests of Wisconsin, the Ucraina steppe, the meadows and marshy grasslands of Montelago near Camerino (central Italy) a series of maps, produced in subsequent years, shows the trend of the process which eliminated the different types of natural vegetation (Figs. 12.7, 12.8 and 12.9). In historic times, forests covered the whole territory of the Rio Camacho basin, Bolivia, while today—because of severe deforestation—only 4.3 % of the territory is occupied by forests (Liberman Cruz and Pedrotti 2006). These fragmented and isolated forests are named “residual forests,” whereas the expression “relictual forests” indicates residual and isolated woodland fragments of phytogeographical importance, such as the *Pinus nigra* woods of Villetta Barrea (in the Abruzzo region).

Elimination of entire forests has occurred in many instances; for example, in huge strips of the Sibillini mountains and in many other locations of the central-southern Appennines. In Italy, over the course of the centuries, the vegetation of the river has also been eliminated to make room for agriculture. Nowadays, along water courses, only narrow strips of *Salicetum albae* and other similar associations can be found, whereas, other associations, such as those of *Populus alba*, *Ulmus campestris*, *Fraxinus angustifolia*, *Quercus robur* and other

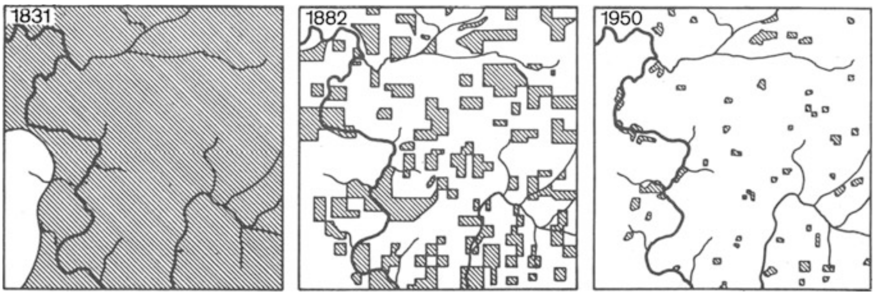

Fig. 12.7 Maps of parceling, fragmentation and disappearance of a forest in Wisconsin, USA (from Faliński 1998)

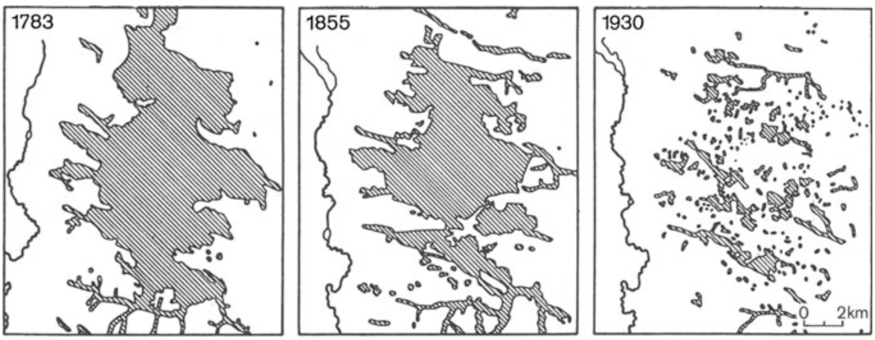

Fig. 12.8 Maps of parceling, fragmentation and disappearance of a steppe in Ukraine (from Faliński 1998)

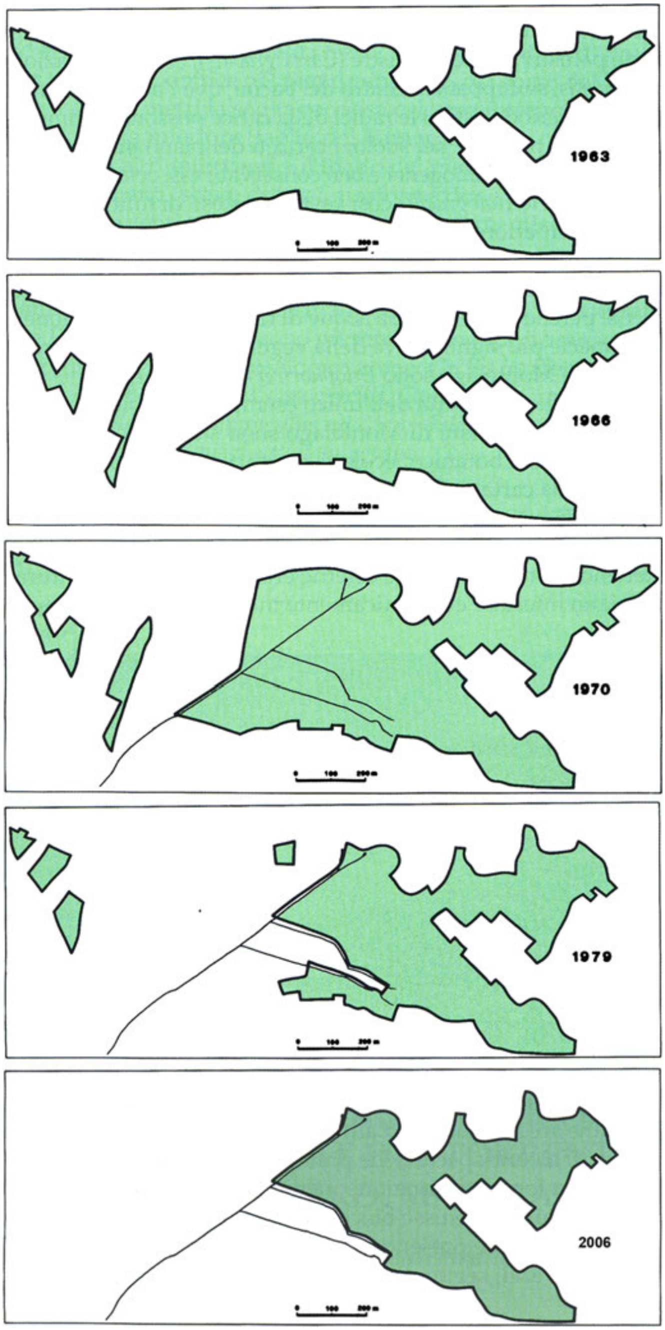

Fig. 12.9 Maps of parceling, fragmentation and disappearance of the grasslands of Piano di Montelago, Camerino, Marche (among which *Hordeo-Ranunculetum velutini*), following tillage interventions (survey by F. Pedrotti)

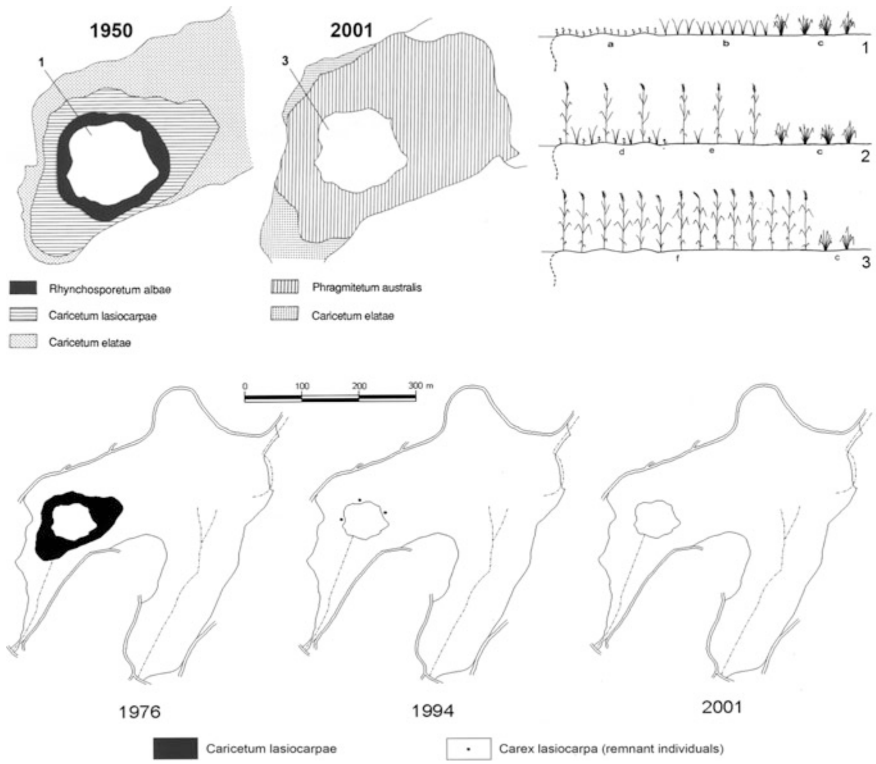

Fig. 12.10 Progressive reduction and disappearance of a few peatland and swamp associations in the Laghestel di Piné (Trentino, Northern Italy). *Top* from 1950 to 2001, disappearance of *Rhynchosporetum albae* and *Caricetum lasiocarpae* and strong expansion of *Phragmites australis*; *a—Rhynchosporetum albae*, *b—Caricetum lasiocarpae*; *c—Caricetum elatae, d—Rhynchosporetum albae* and *Caricetum lasiocarpae* with invasion of *Phagmites australis, e—Caricetum lasiocarpae* with invasion of *Phagmites australis, f—Phragmitetum australis*; *bottom* map of the *Caricetum lasiocarpae* in 1976. This species disappeared because of water eutrophication; in 1994 only a few isolated plants were observed. In 2001 the species was completely eliminated from the area (local extinction) (from Pedrotti 2004)

species have almost totally disappeared without a trace. Only a few locations still host riparian forests, which, given their residual character, are presently of enormous interest. Such locations can be found along the Mincio river, at San Rossore, Persano, along some tracts of the Ofanto river and in few other cases (Pedrotti and Gafta 1996).

Finally, here is an example of the changes occurred in the phytocoenoses of an oligotrophic mire named Laghestel di Piné (in the Trentino region). Such changes were due to eutrophication caused by pollution of the waters, which feed the mire (Fig. 12.10). In the past, the mire was characterized by a ring of vegetation of transitional peat bogs formed by floating associations ("aggallati") of *Rhynchosporetum albae* and *Caricetum lasiocarpae* with different species of peat

Fig. 12.11 The vegetation of the mire of Laghestel di Piné in 1970, formed by *Caricetum elatae* and *C. lasiocarpae* (from Pedrotti 2004)

mosses. In a few years' time (from 1976 to 2001) the floating associations completely disappeared, including the rare species which they hosted, namely: *Rhynchospora alba*, *Carex lasiocarpa* and all the peat moss species (*Sphagnum recurvum*, *S. palustre*, *S. magellanicum*, *S. teres*, *S. subsecundum*). They were replaced by a huge and dense cane thicket (*Phragmites australis*), as it is highlighted in the cartographic survey (compare also Figs. 12.11 and 12.12).

Mapping threatened vegetation series: A sigmetum is a quantified spatial expression of all the homogeneous vegetal groups of a series, which are present in a tesela. This term makes reference to a territory characterized by sufficient ecological homogeneity and capable of hosting a single mature grouping representing the climax (Géhu and Rivas Martìnez 1981). In this regard, sigmetum is synonymous with vegetation series. A sigmetum represents the vegetation spatiotemporal integration. An example of sigmetum is constituted by the beechwood of Monte Bondone (in the Trentino region) where the more mature association is the *Cardamino penthaphylli-fagetum,* bush associations (*Salicetum capreae*, *Cotoneastro integerrimi-Amelanchieretum ovalis* and *Rubetum idaei*), megaphorb vegetation (*Senecio vulgaris*-*Epilobietum angustifoli*) and herbaceous associations (*Scorzonero aristatae*-*Agrostidetum tenuis*) (Fig. 12.13) are also part of this series. Beechwood is the original vegetation of this tesela (constituted of calcareous rocks of the upper mountain region in the pre-alpine sector). However, secondary grasslands of the association *Scorzonero*-*aristatae*-*Agrostidetum tenuis*, which have been regularly grazed and mowed until few years ago, have been obtained through deforestation. Following the abandonment of livestock farming, grasslands underwent a process of secondary succession, with the development of the two shrub

Fig. 12.12 The vegetation of the mire of Laghestel of Piné in 1994, formed by *Phragmitetum australis* (from Pedrotti 2004)

associations. In Fig. 12.13, the effect caused by disturbance (forest cutting) with the subsequent formation of a clearing and secondary vegetation has been highlighted.

As earlier mentioned, every sigmetum, with the exception of primary grasslands, is defined by the forest association by which it is characterized. The other associations are those which precede forest or follow it, after its destruction by human intervention or natural events (flooding, volcanic eruptions, etc.). In the first stages they are formed by herbaceous species (mainly grasslands), chamaephytes (heath and maquis with low-growing shrubs) and shrubland, whereas trees (forests) constitute the final stage. Forest fluctuates between the two extremes of the sigmetum: on one extreme forest is absent, on the other is present; in the intermediate stages, forest may be expanding or contracting, because of human intervention. In our time, forests are either absent or characterized by a small extent, whereas, in prehistoric times and beyond, forested areas covered huge territories. Nowadays, vast areas have been subjected to deforestation and forests persists only in residual areas, such as mountain chains and few other locations.

The cartographic representation of sigmetum is performed through integrated phytosociological maps (spatiotemporal integration) on which sigmeta (or vegetation series) are showed. Many are the opportunities provided by the use of sigmeta for environmental evaluation. However, until now, they have not been subjected to a thorough experimental evaluation.

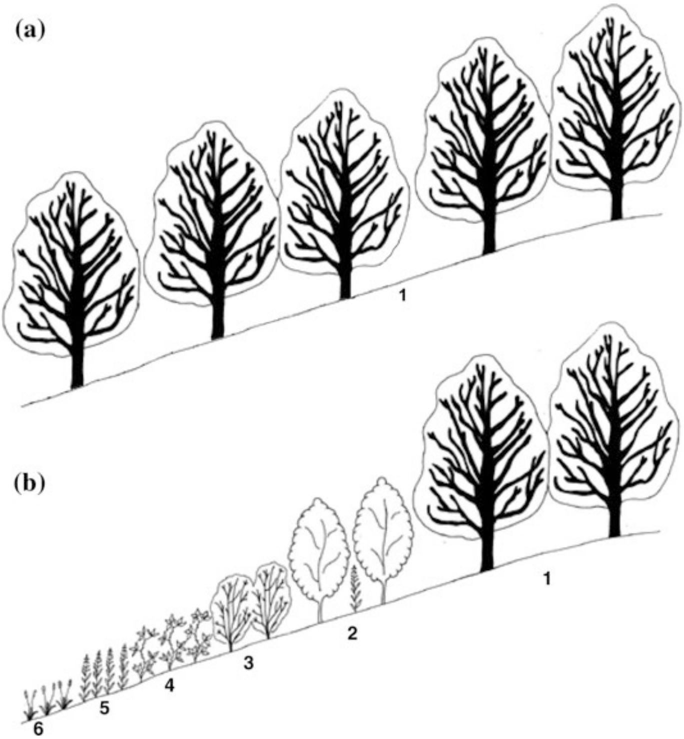

Fig. 12.13 **a** Vegetation series of *Fagus sylvatica* (*Cardamino pentaphyllo*—*Fageto* sigmetum), Monte Bondone, Trentino, Northern Italy; here only the more mature association, i.e., the forest, is showed. **b**—the same series with all the associations included *1*—forest (*Cardamino pentaphyllo-Fagetum*), *2*—shrubland (*Salicetum capreae*) *3*—shrubland (*Cotoneastro-Amelanchieretum ovalis*); *4*—shrubland (*Rubetum idaei*) *5*—megaforb vegetation (*Senecioni sylvatici-Epilobietum angustifolii*) *6*—grassland (*Scorzonero*—*Agrostidetum tenuis*) (from Pedrotti 1996)

Mapping threatened landscapes (geosigmetum): Geosigmetum (also called geo-series or geosigmassociations) is the quantified spatial expression of all the plant communities of a catena, i.e., belonging to a group of sigmeta (or vegetation series) which are in close contact to one another within a great geomorphological unit, for example, mountain slopes and valleys (Fig. 12.14). Therefore, geosigmetum gathers the complete altitudinal sequence of the vegetation series of a catena (Géhu and Rivas Martinez 1981). As previously mentioned, according to geosynphytosociology, vegetated landscape is formed by geosigmeta (Fig. 12.15) which can be easily mapped.

Geosynphytosociological maps constitute the basis for disturbance surveying and mapping at landscape level. Two types of impact are recognizable, namely the historical and the current one. Historical impact is related to human intervention on natural environment through deforestation, creation of cleared and cultivated areas,

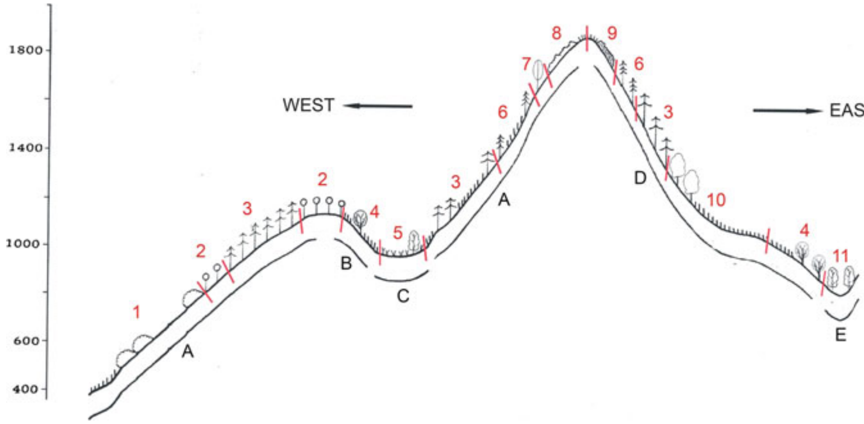

Fig. 12.14 Spatial relationships among vegetation series and geoseries, Piné, Trentino, Northern Italy; series (sigmeta): *1—Fraxinus ornus* and *Ostrya carpinifolia* series [*Fraxino orni-Ostryeto carpinifoliae* sigmetum], also formed by the *Tunico-Koelerietum gracilis* association; *2—Pinus sylvestris* series [*Vaccinio vitis-idaeae* sigmetum]; *3*—mountain series of *Picea abies* [*Luzulo-Piceeto* sigmetum], also formed by the *Sieversio montanae-Nardetum* association; *4—Quercus petraea* series [*Luzulo niveae-Querceto petraeae* sigmetum], also formed by the *Melandrio-Artrhenatheretum* association; *5*—swamp series of *Alnus glutinosa* [*Carici elongatae-Alneto glutinosae* sigmetum], also formed by the *Caricetum elatae* association; *6*—sub-alpine series of *Picea abies* [*Homogyno-Piceeto* sigmetum], also formed by the *Sieversio montanae-Nardetum* association; *7—Pinus cembra* series [*Larici-Pineto cembrae* sigmetum]; *8—Rhododendron ferrugineum* series [*Rhododendron ferruginei* sigmetum]; *9—Juniperus nana* series [*Junipero-Arctostaphyleto* sigmetum]; *10—Fagus sylvatica* acidophilous series [*Luzulo-Fageto* sigmetum], also formed by the *Melandrio-Arrhenatheretum* association: *11—Alnus incana* series [*Alneto incanae* sigmetum]; geoseries (geo-sigmeta); *A*—geo-sigmetum of west-exposed slopes, formed by sigmeta 1, 2 and 3; *B*—geo-sigmetum of east-exposed slopes formed by sigmetum 4; *C*—geosigmetum of flat valley bottoms, formed by sigmetum 5; *D*—geo-sigmetum of east-exposed slopes formed by sigmeta 3, 6, 9, 10; *E*—geo-sigmetum of watercourse beds, formed by sigmetum 6 (from Pedrotti 2015, modified)

and the construction of settlements and communication routes in historic times. The current type of impact is related to the great anthropic modifications of the modern time, entailing the construction of structures and infrastructures almost everywhere. Environmental impact cartography is considered a relatively complex topic. Indeed, it has received no definite systematization, in contrast with what has happened in geological and botanical cartography.

A first possibility would be the construction of separated maps, one for each type of disturbance, as Martinelli (1990) did for the Camerino territory (central Appennine). In this case 21 themes were surveyed and displayed on a separate map; 15 were related to the natural environment (ridges, conoids, erosion grooves, etc.) and 6 to anthropic impact (cultivations, forests which are seemingly all fragmented, quarries, pastures, mountain meadows, human settlements and reforested areas) (Fig. 12.16).

Fig. 12.15 Eastern slope of Mount Bondone from m 245 (valley bottom) to m 2176 (Cornetto Peak of Monte Bondone, Trentino, Northern Italy); vegetated landscape formed by a vegetation catena (or geo-sigmetum) including: *1*—*Seslerion albicantis* sigmion; *2*—*Erico-Pinion mugo* sigmion; *3*—*Cardamino pentaphylli-Fageto sylvaticae* sigmetum; *4*—*Cardamino pentaphylli-Abieteto albae* sigmetum; *5*—*Carici albae-Fageto sylvaticae* sigmetum; *6*—*Fraxino orni-Ostryeto carpinifoliae* sigmetum; *7*—*Celtidi australis-Querceto ilicis* sigmetum (from Cristea et al. 2015, modified)

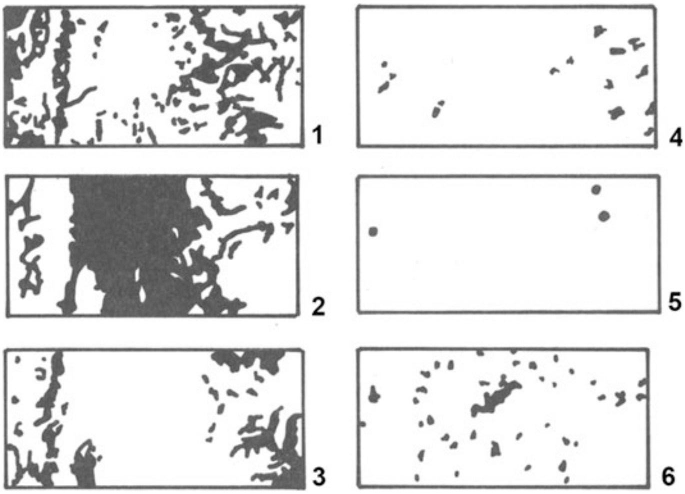

Fig. 12.16 Anthropic impact on the Camerino territory, central Apennine. Each type of disturbance is represented by a different map: *1*—Coppiced woodlands of deciduous trees (which are currently undergoing a process of fragmentation); *2*—cultivated areas; *3*—mountain pastures; *4*—reforested zones; *5*—quarries; *6*—urban areas (from Martinelli 1990)

For the Stelvio National Park three maps have been surveyed: two are related to the historical impact (vegetation and human settlements) and one to the recent anthropic modifications, such as hydroelectric power plants, water canalizations, electroducts, cableways, development zones of built-up areas, quarries and mines (Pedrotti et al. 1969; Patella 1969; Pratesi 1969).

A second option would be the construction of an exhaustive map representing, by overlapping, the various themes surveyed in a given territory; such a method, though, has not given satisfactory results for technical and graphic reasons, due to the difficulty in reading a map full of many symbols and different colors (Ozenda 1974; Journaux 1975).

It should also be pointed out that the maps dealing with the anthropic impact on the environment are conceptually different from the environmental maps. Environmental cartography is a large topic which is not pertinent to the present discussion. However, some brief considerations will be made, particularly about cartography of anthropic disturbance.

Presently, the method that seems more suitable for the cartographic representation of the environment is based on synthetic cartography through the recognition of synthetic spatial units, called environmental units. These are territorial portions, which are synthetically defined for cartography and relatively homogeneous under different point of views: the physical environment (with all the aspects concerning geomorphology, pedology and climate), the vegetation mosaics, the anthropic impact (direct or indirect). Thus, environmental units can be framed within higher systems of classification, by the identification of systems and subsystems. The map of the environmental units of the Stelvio National Park at scale 1:50,000, shows 37 environmental units. Each one carries a definition (periphrasis) providing the essential characteristics of the unit, a description and a symbol (Pedrotti et al. 1997; Gafta and Pedrotti 1997). Twelve of these units are the consequence of anthropic disturbance: typical huts for summer use by herders (“malghe”) and surrounding grazing clearings called “campivoli”, terraces with mowable meadows and temporary “masi”, typical alpine buildings used for housing or for stabling, temporary villages with mowable meadows, clearings with permanent “masi”, mowable meadows and cultivated areas, half-slope inhabited built-up areas with mowable meadows and small cultivated areas, slopes with meadows and enclosed fields (“bocages”), conoids with houses, cultivated areas and mowable meadows, pastures on the lower mountain slopes, surrounding areas of rural settlements, intensely cultivated areas located in valley bottoms, *Larix decidua* pastures, more or less urbanized rural areas (Fig. 12.17).

The same methodology has been employed for the environmental maps of the Monti Sibillini National Park and for the Abruzzo, Latium and Molise National Park (Pedrotti 1999; Martinelli 2013).

In my opinion, the maps related to plant synanthropization can be reconnected to such a category because of progressive invasion and diffusion of neophytes and other ruderal, nitrophilous and ubiquist species. In Poland, Faliński (1998) has constructed, with traditional methods, a map of the anthropic modifications occurred in local vegetation; a European map of the level of invasion of alien

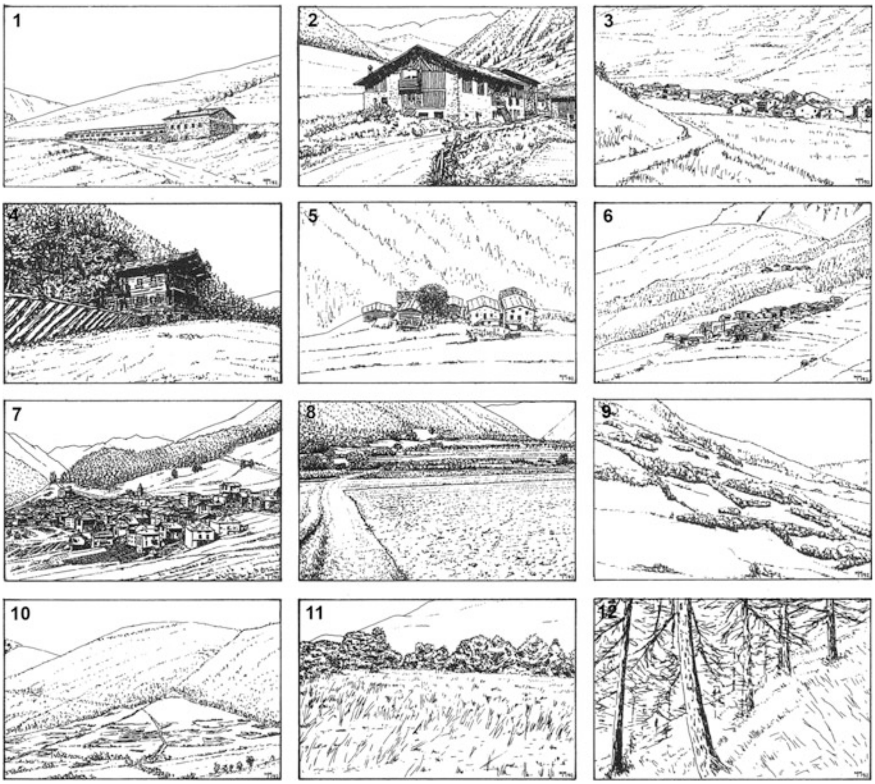

Fig. 12.17 Environmental units of the Stelvio National Park, central Alps: *1*—“malghe” and surrounding grazing clearings, *2*—temporary “masi” and surrounding lawn clearings; *3*—temporary villages for summer use; *4*—permanent houses and surrounding grazing and lawn areas *5*—built-up areas and surrounding lawn and cultivated areas; *6*—small villages and surrounding lawn and cultivated areas; *7*—villages; *8*—intensely cultivated areas located in valley bottoms; *9*—meadows delimited by hedges and forming enclosed fields (“bocages”); *10*—conoids with lawn and cultivated areas; *11*—secondary pastures; *12*—*Larix decidua* pastures (from Pedrotti et al. 1997)

species as a consequence of human influence has been devised by Chytry et al. (2009) and has been based on assessment across the habitats. These two maps are significant examples of the above-mentioned synthetic cartography. Seven stages of synanthropization are comprised in the Poland map and have been attributed to predefined geographical meso-regions; the European map is related to three levels of neophyte invasion: less than 1 %, 1–5 %, more than 5 %.

Mapping threatened habitat: A habitat constitutes the environment in which organisms and ecosystems live. As an ecological concept, it includes species, communities as well as the biotic and abiotic conditions present in the area under consideration (Géhu 2013). A list of priority habitats has been approved by the European Community and they have been protected under specific directives.

However, many problems lay unsolved about the definitions and nomenclature adopted by the European Community. In the first place, one should recognize that speaking about "habitat" is incorrect, since, as pointed out by Petrella et al. (2005), there are many habitat "types". In the second place, the European classification has been based on the phytosociological classification of vegetation, the Corine Biotope (Commission of the European Community 1999). Habitats, though, have been defined in a very heterogeneous and confusing way, according to three modalities: (1) by indicating a type of environment (for example, coastal lagoon, etc.), (2) a type of environment in relation to species or vegetation (dunes with *Hippophaë rhamnoides*, alpine brook with *Myricaria germanica*), a vegetation formation (oro-mediterranean pinewood), a vegetation formation in relation to individual species (Apennine beechwood with *Taxus* and *Ilex*), (3) a phytosociological unit (*Luzulo-Fagion* beechwoods). With reference to geo-synphytosociology, Boullet and Gaudillat (2015) point out that habitats, as identified by the European community, are related to the following levels of geobotanical knowledge: area of presence of a species, phytocoenosis, vegetation series, vegetation geoseries.

In order to try to avoid such misunderstandings, the member states of the European Community have been forced to publish habitat interpretation manuals (for Italy, see Blasi et al. 2010).

Habitat cartography consists of environmental and vegetation maps. It has a mixed character since the two methodologies are based on different principles: the environmental map is synthetic whereas the vegetation one is analytical. On a practical point of view, two distinct maps can be produced, namely the environmental map showing the delimitated areas occupied by the different habitat types, and the vegetation map showing the delimitations of the vegetation units. These two maps can be easily overlapped in a single document. Habitat delimitations have an important juridical side, in view of their protection. On the contrary, the purpose of vegetation delimitations is scientific, because they allow us to recognize which type of vegetation we can find in the different habitats. The assessment of the conservation status of the vegetation constitutes the subsequent step.

It would be preferable to speak of habitat vegetation cartography and not only of habitat cartography, because the two methodologies are well separated. The vegetation cartography is a type of scientific cartography; from a theoretical point of view, the habitat cartography is a type of scientific cartography as well. Nevertheless, it acquires a practical value in the case of priority habitats, because the term "habitat" is employed only in juridical terms, for the purpose of their protection.

Mapping natural disturbance: Natural disturbance is the result of processes which normally occur in nature. Accordingly, its assessment raises no particular problems,

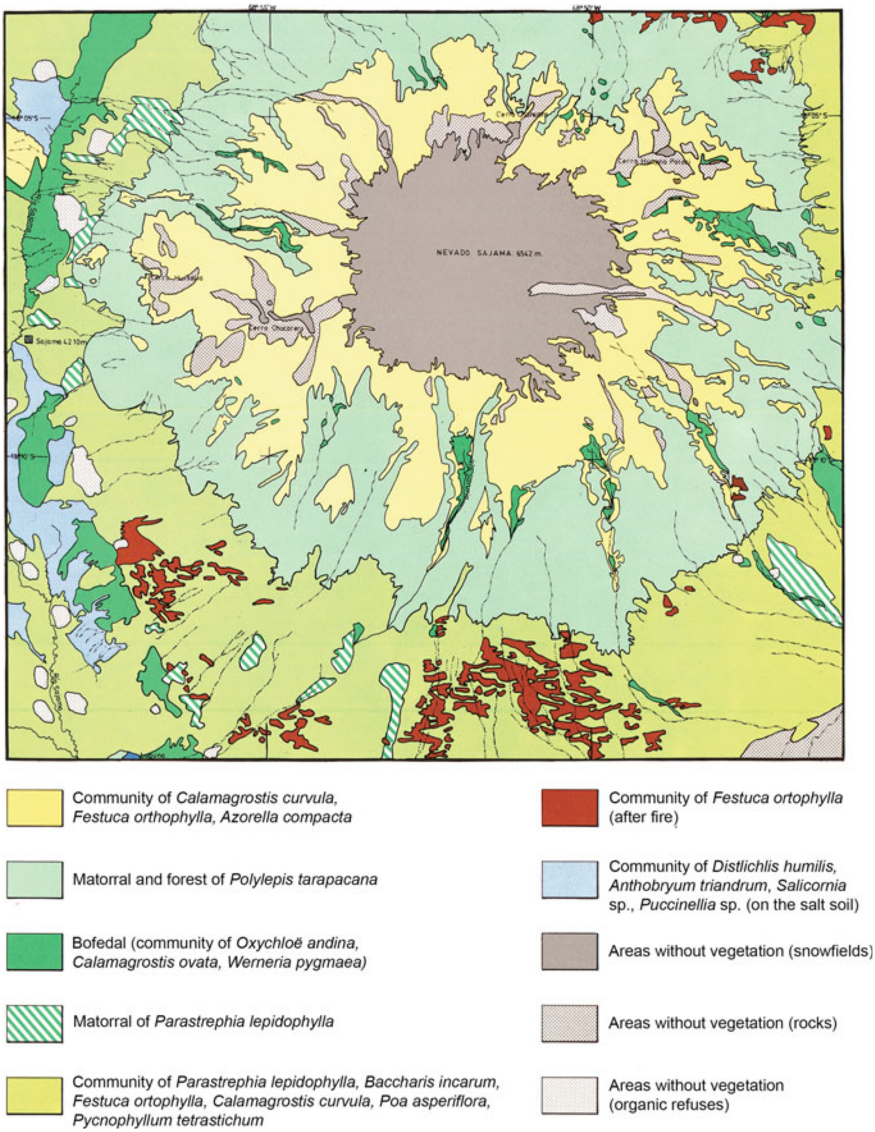

Fig. 12.18 Vegetation map of Nevado Sajama, an extinct volcano in the Bolivia's highland plateau; vegetation tend to develop on the volcanic cone in concentric rings. The matorral belt of *Polylepis tarapacana* is clearly shown. It is interrupted by lava flows and deposits of volcanic debris on which an open herbaceous vegetation have developed. It is a pioneer vegetation formed by *Calamagrostis curvula*, *Festuca ortophylla*, *Azorella compacta*, *Pycnophyllum molle* and few other species (from Liberman Cruz 1986)

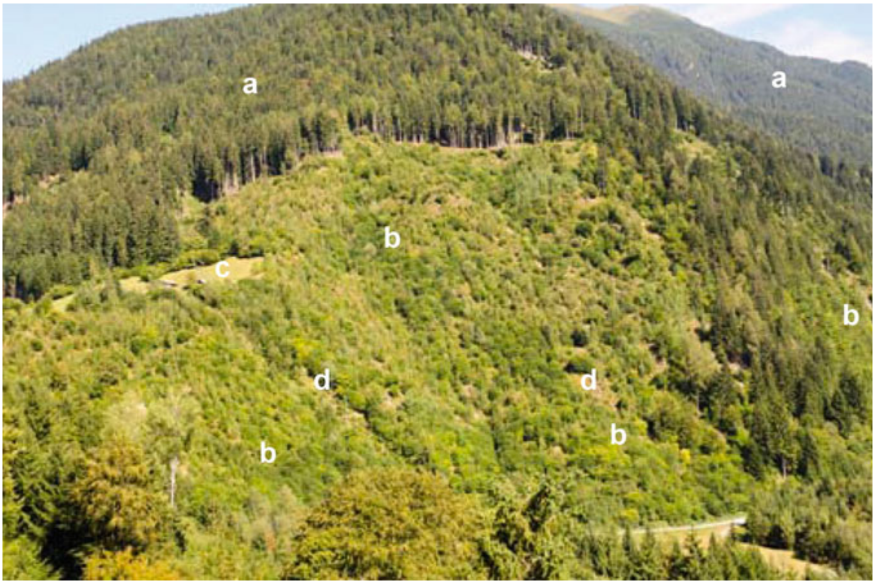

Fig. 12.19 Val Calamento, in the Trentino (Northern Italy). Clearing caused by a whirlwind in the mountain forests of *Picea abies* belonging to the *Luzulo-Piceetum* association (*a*); shrublands of *Rubus idaeus* (*Rubetum idaei*) and *Salix caprea* (*Salicetum capreae*) have developed; (*b*) letter (*c*) indicates a little clearing with herbaceous vegetation, which was present before the occurrence of the storm (from Pedrotti 2013a)

except those related to vegetation cartography. For a discussion of the theoretical and practical aspects of such problems, I refer you to the general publications previously mentioned.

The great natural events, like landslides, volcanic eruptions, wind, etc., share a common characteristic: they are capable of destroying preexisting vegetation and give origin to a new environment, with no animal and plant, devoid of organic substance and soil, made available for pioneer and colonizing species. In this section, some examples related to the principal events of natural disturbance will be presented as a general overview of the subject.

Landslides occur on mountain chains and debris deposits constitute an environment where the process of primary successions soon begins. These are characterized by pioneer associations with a very low degree of cover and capable of developing toward the formation of soil and wood. As far as soil and vegetation are concerned, a well-known example of this type of primary succession concerns the limestone debris accumulated in the valley bottom near Dro village, in the Sarca Valleys (Trentino) and locally called "marocche" (Pedrotti et al. 1996). The succession starts with an associations of ferns (*Asplenietum trichomano-rutae-murariae*), goes on with the *Stipetum calamagrostidis* (associations of herbaceous species) and the *Cotino-Amelanhieretum ovalis* (shrubs) and terminates with the

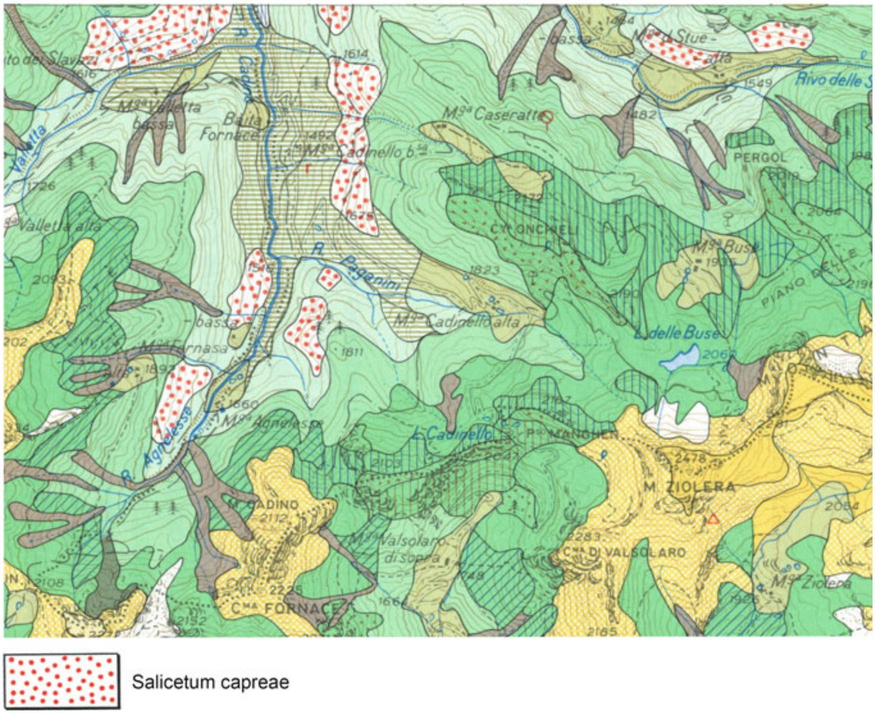

Fig. 12.20 Vegetation map of Val Cadino, Lagorai (Trentino, Northern Italy); in the areas where a big storm has destroyed the tree layer of the original forest corresponding to *Luzulo-Piceetum*, a *Salicetum capreae* association has developed (from Pedrotti 1988)

Fraxino orni-Ostryetum carpinifoliae. The initial stage of the pedogenesis is a rocky peyrosol a few centimeters thick, which leads to a moderately deep rendosol.

Avalanches are also endemic to the mountains, particularly at high altitudes; they normally go downhill along gullies, which carve the mountainsides, as it is showed on the Rabbi Valley avalanche map made by Albertini (1951). By comparing such a map with a vegetation map (Pedrotti et al. 1974), it can be noted that the distribution of *Alnus viridis* associations coincide with that of the gullies which interrupt the slopes occupied by Norway spruce (*Picea abies*) forest belonging to *Homogyno-Picetum* in the upper mountain region, and *Luzulo Picetum* in the lower mountain region.

Volcanoes constitute the typical environment where, due to eruptions and lava flows, geomorphological landscape continuously change and where, on the newly formed deposits, the processes of primary successions take place. Vegetation tends to be arranged into concentric rings (see, for example, the vegetation map of the Mount Etna, Poli Marchese and Patti 2000) interrupted by lava flows on which a pioneer vegetation will establish itself and undergo a process of evolution over a more or less extended period of time (Fig. 12.18).

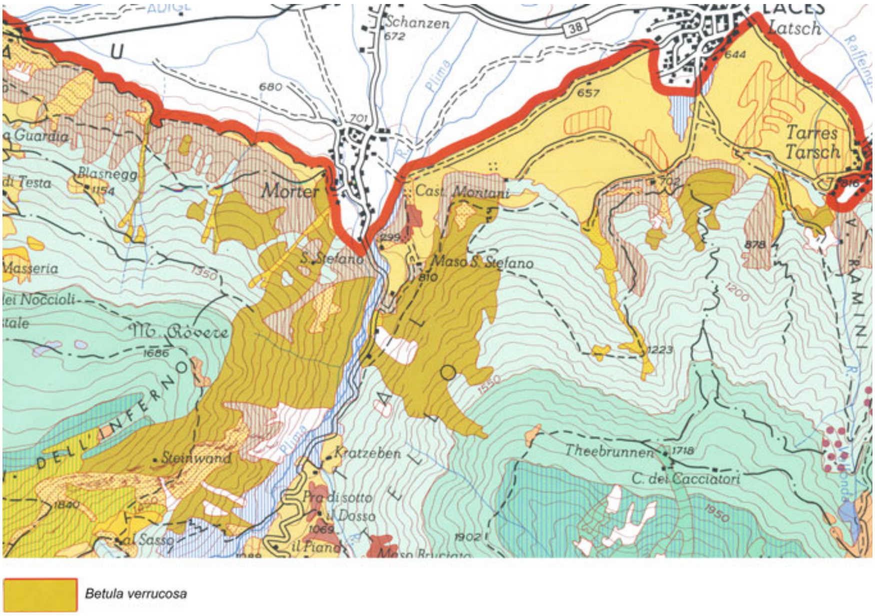

Fig. 12.21 Vegetation map of the Stelvio National Park, central Alps; in the areas affected by forest fires *Betula verrucosa* has grown (from Pedrotti et al. 1974)

The study of the lava flow dynamic processes are of particular interest. In fact, since the date of the lava flow is known, they can be followed from the beginning, as pointed out by Poli Marchese et al. (1996) for Mount Etna and by Neshataeva (2014) for the Kamtchatka volcano. In the latter case, three maps were made: the first before the eruption (1971), the second shortly after (1977) and the third a few years later (2010).

The wind action on vegetation is of great importance and is exerted in many ways. I would only like to mention the whirlwinds, which in summer months hit the pre-Alpine fringe. They exert marked effects on forests, which can be totally wiped out (Venanzoni 1989), although in restricted areas (Fig. 12.19).

A process of secondary succession starts in the clearings created by wind. Initially, herbaceous vegetation establishes itself with the association *Senecioni sylvatici-Epilobietum angustifolii* (temporary and short-lived) which is followed by *Rubetum idaei* (temporary as well) and finally by *Salicetum capreae*, which maintains itself for a very long period of time, before forest returns. Mapping wind-induced clearings is a very easy task by the aid of aerial photography (Fig. 12.20).

I would also like to mention fire, which in some locations on earth surface is a natural phenomenon. Fire ecology is a well-known topic and so are the effects caused by fire (see, for example, Mazzoleni and Aronne 1993; Chiatante et al. 2006; Guglietta et al. 2011 etc.). In Europe, mapping fire-affected areas is not particularly

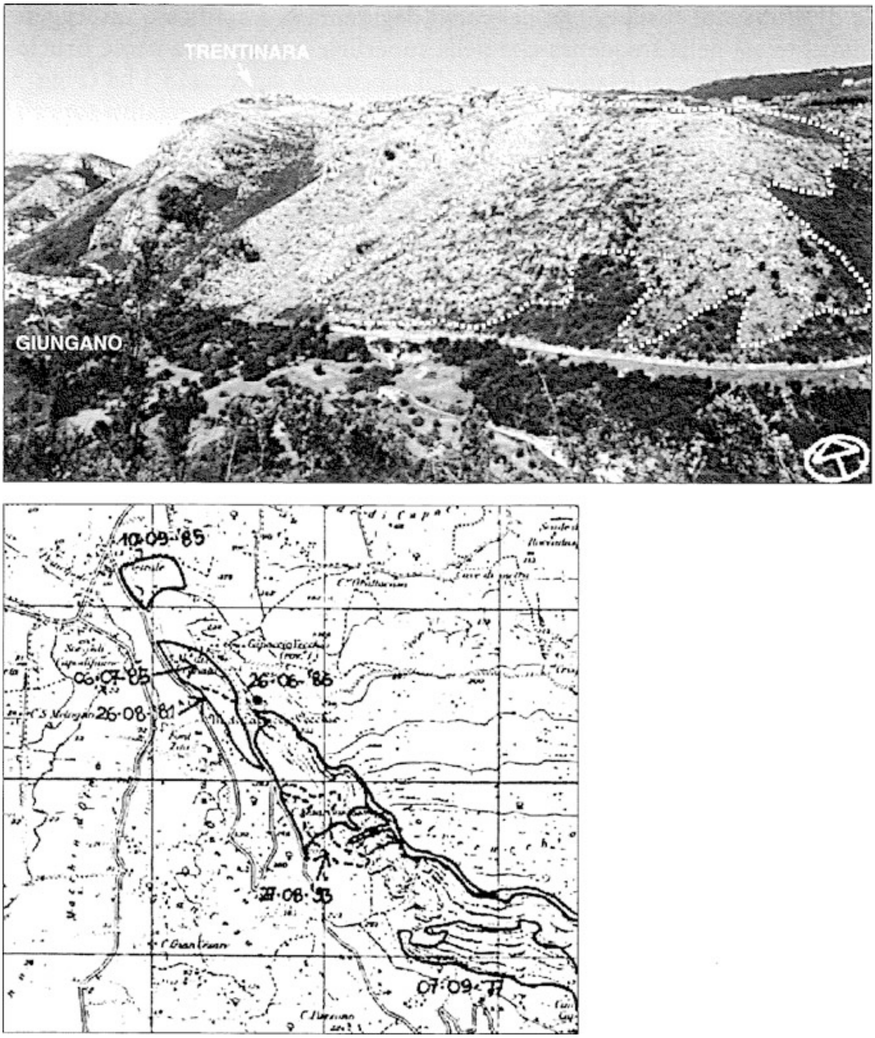

Fig. 12.22 Contour line of fires reported on the map, Campania, Southern Italy (from Mazzoleni et al. 2001)

problematic. It can be performed by the aid of aerial photography, as illustrated in Fig. 12.21, which is related to Val Venosta in the Stelvio National Park. In such a location, slopes are usually occupied by different coniferous associations (*Pinus sylvestris*, *Larix decidua*, *Picea abies*) and the clearings caused by fires (recurrent in the past) are soon invaded by a thick formation of *Betula verrucosa*. In the *Picea abies* forests of Komi taiga (northern Russia) the same kind of dynamism takes after

Fig. 12.23 Zebras grazing in the savannah area where controlled fire was managed (the Kruger National Park, South Africa; *Photo* Franco Pedrotti)

the fire, with development of forests initially dominated by deciduous trees (*Populus tremula, Betula verrucosa* and *B. pubescens*) and subsequently replaced by *Picea abies* (Tarvainen 2007). All the comparison between the photographic documentation of a fire-affected zone and its cartographic representation is also worth of interest (Fig. 12.22).

In other countries, where fires spread through extensive areas, such as Australia and South Africa, cartographic representation becomes more problematic for several reasons, among which the lack of a detailed vegetation typology. In the Kruger National Park (South Africa), regular prescribed burning is practiced to keep the sparse tree vegetation (which also comprises *Colophospermum mopane*) under control. This practice facilitates the observation of herbivorous animals (Figs. 12.23 and 12.24) and the development of herbaceous species, which constitute their principal food source. For such a reason, Kruger landscapes are partly natural and partly modified by man through prescribed burning. The cartographical monitoring of these areas is not worth of interest since they are very large and homogeneous.

In various European countries, among which Italy, a debate has been engaged about the possibility to introduce controlled forest burning. Although this technique

Fig. 12.24 Savannah subjected to controlled fire in the Kruger National Park (South Africa). Among species of shrubs and trees, two plants of mopane (*Colophospermum mopane*) are shown with burning leaves but still carried from the plant. In the clearings the herbaceous species are growing vigorously after the fire (*Photo* Franco Pedrotti)

might be useful in order to eliminate the dry remnants of herbaceous and woody plants and prevent summer fires, the hypothesis has raised skepticism among most forestry technicians and botanists.

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