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Corrado Battisti
Gianluca Poeta
Giuliano Fanelli

An Introduction to Disturbance Ecology

A Road Map for Wildlife Management and Conservation

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Corrado Battisti · Gianluca Poeta
Giuliano Fanelli

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Corrado Battisti
Protected Areas Service
Città Metropolitana di Roma Capitale
Rome
Italy

and

Department of Science
University of Rome III
Rome
Italy

Gianluca Poeta
Department of Science
University of Rome III
Rome
Italy

Giuliano Fanelli
Department of Biology
University of Rome II Tor Vergata
Rome
Italy

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Preface

The effects of human activities are everywhere evident on a wide portion of our planet. More particularly, some geographical areas are strongly characterized by a pervasive and age-old presence of *Homo sapiens*. Together with the modifying agents of natural origin (properly called the *disturbances*), our species has heavily shaped the landscape and natural ecosystems through historical and recent processes characterized by different modes, extent and intensity. The anthropogenic processes that interfere with the structure and dynamics of the *components* and the *environmental systems*[1] have been defined as *threats*.

The processes of threat are noticeable, directly or indirectly, even in *sites* and *areas*[2] of great natural interest (e.g., protected areas, Natura 2000 sites, oases of environmental associations). Consequently, those who manage these areas must necessarily obtain information on the anthropic system in all its complexity, gathering data about the presence, location, extent and intensity of works, infrastructures, and human activities as well as the possible threats triggered by these processes. A thorough analysis of the impacts on the environmental components that constitute the primary value of the sites under management must be carried out.

Practitioners and professionals working in the management of these areas give a series of goals and develop specific strategies and actions aimed at the conservation of certain *targets* or components of the environment that have been identified by the scientific community and the regulatory policy to have a specific value. The strategies pursued in these sites may be conducted in an ordinary way by the

[1]In the land use science, the *environmental component* is any biological or ecological unit that characterizes an environmental *system*. Individuals belonging to a given population, the populations of certain species within certain ecological communities (biocenoses), the biotic communities inside certain ecosystems, ecosystems placed in landscapes are examples of environmental components that structure hierarchically superior systems.

[2]In the text we will refer to the terms of *site* or *territorial area* to indicate, in a heterogeneous way, discrete portions of territory (respectively of limited or wider extension), which are taken by a team of experts as unit of evaluation, management, planning, design or conservation (private properties, public areas, fragments of habitat, areas with different protection scheme, etc.).

continuous and constant engagement of local institutions. Consultation from external professionals can be integrated to provide advice in the development and management of specific projects and the plans of management.

Both technicians from local institutions and external professionals need to frame the complex regional (eco)system applying a variety of conceptual and operational approaches able to understand the phenomena that occur on the site. However, the understanding of the structure and dynamics of a territorial system requires the knowledge of both the components that make up the biological diversity and all those factors and threat processes posed by human activities. The analysis of the relationships with the environmental components should be performed considering the past, present, and future threats. This wealth of knowledge, together with the analysis and comparative evaluation, is essential. It allows to check the status of conservation of the ecological components and the extent of pressures and impacts on them.

Despite this, most of the tools of conservation (e.g., plans and projects) are still mainly concentrated, at least in our country, on the acquisition of in-depth quantitative and qualitative data of the natural components, with no research and analysis effort on the assessment of the role and effects of the threat processes impacting on the local environmental components. Even when the processes of threat are mentioned, they are introduced in a non-standardized and confused terminology. In addition, the time and space courses of the individual threat events (i.e., their extent, intensity and mode of action, including the impact to the different environmental components identified as priority targets) are not even approximately quantified, measured, or compared in most of the cases. An approximate analysis of pressures and impacts of human activities on the site under investigation may have important consequences in defining strategies for the management and conservation as well as in the verification of effectiveness of plans and projects and in initiating monitoring processes and adaptive management.

Just as a response to these shortcomings, a specific field of conservation biology and wildlife management (defined as *threat analysis*) has caught on in the last few years and now constitutes an important step in the programs implemented by many international organizations (among these, The Nature Conservancy and the World Wide Fund for Nature). This approach to conservation is used in the situations of uncertainty, criticality, and urgency that typically characterize most of the management and conservation contexts (Burgman 2005). This is the case of those sites where many anthropogenic events cause immediate and short-term impacts on environmental components. Despite other analyses have already been established in the past (e.g., the Environmental Impact Assessment), with this new approach, operational tools are provided for a rapid quantification of the events, allowing, through consultations among experts (*expert-based approach*), a comparison and prioritization of threats. All these procedures will allow, once the priorities are defined, to prepare the subsequent steps based on the application of more analytical approaches and priority threat-oriented methods.

The *ecology of disturbance* and the *threat analysis* are disciplines that have recently developed a strong theoretical foundation based on a solid and extensive literature. This book will therefore acts as an introductory document to these issues, providing schematic concepts and approaches useful to work on sites and areas that are impacted by the transforming action of humans.

This volume is addressed to the conservation and environmental practitioners and, more generally, to all who work in the environmental sector. They will find hints and tips for choosing methods and approaches when there are conflicts between the natural components and human activities. All sites subject to management strategies and conservation, with particular reference to protected areas, are privileged areas where the constant presence of operators can monitor and predict the pressure and impact of anthropogenic threats.

The book is also addressed to the students of applied ecology, ecosystem management, land use planning, and environmental impact assessment. In fact, it discusses a number of topics covered in the programs of many university courses related to disciplinary arenas of basic ecology and ecology of disturbance, the latter constituting a field of great interest because of its implications and repercussions in applied land use science.

On such a basis, this book aims to provide some conceptual frameworks useful in operative conditions of all those working in human-made landscapes. In particular, the following topics will be addressed: the issues related to the standard nomenclature of threats, the definition of the causal relationships between the anthropogenic events and environmental components identified as targets of conservation, the fast quantification of threats, and the identification of those regarded as priority. The text is also accompanied by an interesting contribution of Prof. Franco Pedrotti who, from different perspectives, deal with the issues related to the concepts of disturbance, threat, stress, pressure, and impact in vegetation science.

This work will not deal with specific aspects relating to the characterization of individual threats. For this topic, we encourage to read the highly available literature in this field that describes each anthropogenic threat through specific tools, approaches, metrics, and indicators. Finally, this book will not discuss issues about natural disasters, as such events (natural or anthropogenic) affect our species as main target, and therefore, are the subject of other specific disciplines (Table 1).

Table 1 Events on sites of conservation concern. Topic, origin, categories of impacted targets, disciplinary arenas, sciences, main seminal references and location in this book are reported

Topic	Origin	Categories of impacted targets	Arenas	Science	Main (seminal) references	Location in the book
Disturbances	Natural origin	Natural components (secondarily, anthropogenic ones)	Disturbance ecology	Ecology	Pickett and White (1985), Sousa (1984)	Chapters 1–7
Threats	Anthropogenic origin	Natural components	Threat analysis	Conservation biology, wildlife management	Salafsky et al. (2002, 2003, 2008)	Chapters 8–12

(continued)

Table 1 (continued)

Topic	Origin	Categories of impacted targets	Arenas	Science	Main (seminal) references	Location in the book
Disasters, calamities	Natural/anthropogenic origin	Man (secondarily, natural components)	Science of catastrophes, risk analysis	Applied geology, urban security	Alexander (2001)	–

The volume is divided into two parts. The first focuses on the theoretical and disciplinary framework of the ecology of disturbance. The second is devoted to the analysis of anthropogenic threats. The latter, in particular, refers to the most recent approaches that, through the use of a conventional nomenclature, allow a *coarse-grained* quantification and objective assessment of threat impact on different environmental components. Such approach facilitates the comparison between hierarchically different events and, therefore, helps in the definition of priorities for strategies of management and conservation.

The management of the territory and the establishment of actions for the conservation of particular targets or the elimination/mitigation of certain anthropogenic threats requires an interdisciplinary approach, often accomplished by a heterogeneous group of professionals. This book is addressed (and dedicated) to the new generation of *conservation practitioners*, that is, the applied ecologists coming from different cultural backgrounds (naturalists, biologists, forest rangers, agronomists, doctors in environmental sciences, planners, engineers, environmental economists, sociologists, psychologists, historians, anthropologists, geographers). These must necessarily collaborate to identify and compare regional critical issues inside complex ecological systems and to promote effective actions. In addition to a rigorous analytical approach, it is necessary that these professionals adopt, with humility, a holistic and transversal vision in order to interpret the complex relationships between the natural world and the human sphere. All this is synthesized below with a quote by Kroll (2007), published on a major magazine of natural resource management (the Journal of Wildlife Management), with which we introduce the reading of this book.

> We cannot continue to produce researchers who focus on narrow, isolated questions,
> maintains the belief that successful natural resource management
> is dependent solely on rigorous scientific inputs
> and possess neither the motivation not the ability to address complicated problems
> and work collaboratively with other professionals to identify feasible solutions.

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Rome, Italy
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Corrado Battisti
Gianluca Poeta
Giuliano Fanelli

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Contents

Chapter 1
Heterogeneity, Dynamism, and Diversity of Natural Systems

The Complexity in Ecological Sciences

Ecology is the science that studies the relationships among the environmental components. More specifically, its overall goal is describing the natural phenomena, studying the causal relationships between events and identifying the presence of regularities in the processes under investigation. The discovery of these regularities may allow the definition of models, that is, some conceptual, synthetic, and schematic representations symbolizing the complexity of the real world.

In the ecological sciences, as well as in the social sciences, the definition of models and of clear cause–effect relationships may not be immediate, due to the large number of variables, components, and processes that characterize the natural (and anthropogenic) systems, as well as for the high level of intrinsic uncertainty and unpredictability of these systems. For these reasons, 30 years ago the science of complexity was initiated to span across various disciplines, including the ecological, social, and territorial sciences (Bocchi and Ceruti 2007).

The *complexity* distinguishes a large number of phenomena at all scales. Each system, as unit of the whole made up in turn of many components, is characterized by a great number of relations and, therefore, show an intrinsic complexity. The same relationships among the components of a system may also not always be linear (that is, predictable and governed by clear cause and effect mechanisms). Often, in fact, the onset of feedback mechanisms helps to make them even more complex, and the prediction of the evolution of the system itself becomes difficult. In the middle of the twentieth century, a change in the disciplinary thought and in the approach to study the structure and processes taking place within the natural systems began to take shape. Indeed, complexity began to be recognized as a feature of the environmental systems at any hierarchical scale (populations, communities, ecosystems, landscapes). Moreover, it became increasingly evident that the disturbance, both unpredictable and predictable, could play a decisive role in

C. Battisti et al., *An Introduction to Disturbance Ecology*,
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defining the variability (spatial heterogeneity and temporal dynamics) that was observed in these systems.

Ecological systems, being complex systems, are characterized by a *history* of events. In fact, specific events have occurred and occur continuously to make up the unique history of the individual systems within certain geographical areas. These events give rise to the spatial heterogeneity and the temporal dynamism that are observed in all environmental systems. They also contribute to the selection, adaptation, and evolution of organisms, populations, and communities. This occurs, in the most extreme form, in those biological species that depend on the processes of disturbance themselves to complete their life cycle: i.e. the species linked to ephemeral conditions such as those that colonize alluvial sediments or related to extreme environmental stress, such as the flora of the high altitude environments or of the coastal dunes. In the absence of spatiotemporal variability, and therefore with no long historical disturbance cycles, these species would not have evolved.

Following this key to understanding, every environmental system can be considered as a complex system, characterized by its composition, structure, dynamics, and processes as well as by its specific and peculiar history of events with different degrees of predictability.

In this regard, *uncertainty* becomes an aspect that is increasingly considered as an intrinsic element of both the direct understanding of a system with its history and the related interpretations (Keith 2009).[1] In the treatment of complex systems, it is necessary to consider the extent and type of such uncertainty when implementing strategies that require decision-making processes (*decision-making, problem solving*).

The emergence of complexity as an intrinsic feature of environmental systems, and the recognition that the latter are characterized by a history of events, are of particular importance in applied disciplines such as wildlife management, conservation biology, and environmental planning. In these disciplines, professionals work for the definition of specific goals achievable through appropriate actions (plans, projects, and measures) that must take into account the variability, uncertainty, and complexity of the systems (Miller 1993; Kroll 2007).

Environmental Variability

Any environmental *system* is always characterized by its own variability,[2] at any hierarchical level of organization, spatial-temporal scale, and grain of resolution. The *heterogeneity*, or *variability*, can be defined as the modality through which the

[1]See the categories of uncertainty in Keith (2009). Epistemic uncertainty: on the imperfect knowledge of the state of the system; linguistic uncertainty: relative to the incomplete, imprecise and inaccurate language used to describe the state itself.

[2]In the following text, we will refer to the term *environmental, natural* or *ecological system* to denote any unit composed of several components in relation to each other: populations (systems of individual components), community (systems of populations of species), ecosystem (systems of

different components of an environmental system (e.g., the ecosystems in a landscape) are mutually associated in space (*spatial heterogeneity*) and time (*temporal dynamism*). Therefore, heterogeneity is an intrinsic feature of such systems (see Tews et al. 2004; Farina 2006).

The composition and structure of animal and plant populations, the number of species, the trophic levels in a community as well as the distribution and type of ecosystems in a landscape can change in space and time determining the variability observed in the environmental systems. This variability is expressed through specific spatial configurations (or *patterns*) which are dynamic in time. They are determined by historical or current causal processes that may be either natural or anthropogenic (Sousa 1984), and originate both internally and externally to the system.

The *patterns* of heterogeneity can be characterized by progressive changes in their characteristics (i.e., through *gradients* of variation) or by abrupt changes (i.e., sharp *thresholds*).

The processes that lead to this environmental variability may be somewhat *predictable* (*deterministic*) or *unpredictable* and *random* (*stochastic*). The possibility of a spatial and temporal unpredictability of causal processes has suggested a change of approach in ecology. In fact, just on the basis of the new paradigms related to the unpredictability, the classical concepts of climax and state of equilibrium, related to the stable and largely deterministic environment hypothesis, have been recently criticized (Wiens 1989; Krebs 2001). Many recent studies have shown that most of the patterns of heterogeneity observed in environmental systems are not compatible with these models, assigning a greater weight to the mechanisms of non-equilibrium to explain the coexistence of species and the structure of communities and ecological systems (Collins and Glenn 1997).

In particular, the study of processes of disturbance and their recognition as a process common in most environmental systems has enabled a paradigm shift. For example, whereas in the first half of the twentieth century ecologists studying plant communities focused on the description and study of the *successions* (patterns of change of species over time, that is, the *turnover*), more recently a greater emphasis has been assigned to the study of external disturbance events able to unpredictably interfere on a community. These events, discrete in time and space, can in fact interfere at various levels with the biological communities. They can prevent or slow down the achievement of a hypothetical stationary equilibrium stage (the *climax*), in which the composition and structure would be regulated primarily by predictable biological interactions.

So, the concept of climax started not to be a universal model any more, as the systems can never reach a hypothetical final state of equilibrium due to recurrent

(Footnote 2 continued)

biological communities and abiotic components), and landscapes (systems of ecosystems). The systems are equipped with specific properties (defined as *emerging*) that do not depend on the sum of the characteristics of their components, but on the synergistic interaction among them.

perturbation events. Despite the critical aspects, the concept of climax can, however, still be used as a reference model, at least for certain communities and in particular conditions (for example, in the absence of perturbations and at relatively large spatial scales).

The ecology of *disturbance*, which analyzes events specifically destabilizing external environmental systems, has become, therefore, an important area of ecology. The concept of *disturbance*, defined as an event to be studied in its specificity, was introduced in the mid-80s (Pickett and White 1985). Thanks to this concept, environmental systems were considered *complex adaptive systems* that, in addition to comprise a number of components and relationships often not fully determinable (characteristics of *complexity*), are also affected by external processes of disturbance. These last processes can reveal themselves with an extremely variable predictability, inducing specific adaptations and responses (characteristics of *adaptability*)[3] depending on the intensity and modes of implementation.

The events of disturbance can be treated as an articulated set of processes that perturbs the environmental systems and bring about a natural variability observed at different spatiotemporal scales and each ecological level. Such events can be, in turn, influenced by the same natural heterogeneity/variability and are, at the same time, cause and effect of the latter.

The disturbance events (term that we will also use as a synonym for *perturbations*) maintain the environmental systems in a continuous state of non-equilibrium, changing their composition, structure, and diversity, and continuously giving rise to new setups. According to a model widely accepted in the 1970s of the last century, the competition among species may represent a mechanism internal to the community that allows a predictable structure in equilibrium conditions (Sousa 1984; Wiens 1989). However, overcoming this traditional view, and with the acquisition of new paradigms related to the concept of disturbance, such predictability cannot be guaranteed due to the possibility that external perturbative events may prevent the achievement of a hypothetical equilibrium state.

Spatial Heterogeneity and Biological Diversity

The spatial heterogeneity and the temporal dynamism, as determined by external limiting factors and perturbation events, may affect the features and ecological variables of environmental systems (composition, density, species richness, and diversity). The environmental heterogeneity and the temporal dynamism are therefore important predictors able to explain the number and diversity of species in an area.

[3]Another definition of *complex adaptive system* is an open system formed by a number of elements non-linearly interacting and that constitutes a single, organized, and dynamic entity, able to evolve and adapt to the environment through various *feedback* processes (based on "inheritable" changes or through the individual acquisition of learned behaviors; Farina 2006).

Table 1.1 Hierarchical scales of biological diversity (from Whittaker 1972; Magurran 2004; Moreno 2006; Magurran and McGill 2011)

Component	Statement
α-diversity	Species number in a site or community (within-habitat diversity)
β-diversity	Between-habitat diversity: turnover rate of species along environmental gradients in an heterogeneous landscape mosaic. It may be calculated as a ratio between the α and γ components (Wilson and Shmida 1984; Ricotta et al. 2003; Koleff et al. 2003)
γ-diversity	Species number in a group of sites or communities at landscape level. It depends on the α-diversity at site level and from the species turnover among sites (β-diversity)
δ-diversity	Species turnover analogous to the β-diversity but calculated at a larger scale (it corresponds to the species turnover among landscapes and regions)

Environments with high heterogeneity make available a wider range of bio-physical, chemical, and ecological conditions, allowing the presence of more niches, and more species as a consequence. Together with environmental heterogeneity and temporal dynamism there are other important predictors: climate, altitude, latitude, competition, predation, productivity, and disturbance.

The concept of *diversity* within biological communities, expressed through a quantification by indexes (e.g., Simpson, Shannon), includes two components: the first corresponds to the number of species or taxonomic groups (possibly normalized, i.e., the *richness* of species or groups), the second corresponds to their *evenness*, that is, the allocation of frequencies among species (see Magurran 2004; Magurran and McGill 2011 for an extensive discussion of the measures of diversity and heterogeneity in the communities).

Diversity can also be calculated following a spatial hierarchy of scales and using appropriate metrics (α-, β-, γ-diversity; Whittaker 1960, 1972; Contoli 1995; Magurran 2004; Magurran and McGill 2011; Moreno 2006; Table 1.1). According to this hierarchy, the odd Greek letters (α- and γ-diversity) correspond to the number of species present in systems characterized by progressively larger scales, the latter conventionally defined each time (α-diversity or diversity of site: *within-habitat diversity*; γ-diversity: diversity of a geographical area comprising several sites: *regional diversity*). The even Greek letters (β-, δ-diversity) correspond to the comparison, even in time, of *turnover* (replacement) of species between systems (*between-habitat diversity*). The latter metric of diversity, in particular, can provide important information on the indirect environmental heterogeneity of a system: the more heterogeneous an environment is, the higher the degree of replacement (or *turnover*) of species among sites.

The measures of turnover (β-diversity) can be very useful to assess the level of environmental heterogeneity of an area, determined by both natural disturbances and perturbations induced by human activities. The geographical areas that show a high γ-diversity (i.e., a high number of species on a regional scale) comprise sites with a relatively increased (very heterogeneous) α- (diversity site) and/or β-diversity (diversity of *turnover*).

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Chapter 2
The Concept of Disturbance

Disturbances are a set of events that can disrupt any ecological level, environmental component as well as the organizational status of a biological cycle of organisms (Pickett et al. 1989). They are an important aspect in the natural selection and the whole biological evolution, as they modify the environment in which every living being performs its vital functions (Krebs 2001). The effects of disturbance can indirectly pass on other components of the environment, ecosystems, and processes. Even the biological, ecological, and behavioral characteristics of an organism can be a disturbance to other organisms, creating a seemingly endless chain of relationships and perturbations among the different components of an ecosystem.

In ecology, the concept of disturbance is crucial. It is closely related to the concepts of stability, diversity, resistance, resilience, and entropy of the environmental systems and is the basis of theories explaining the mechanisms of species coexistence in the community (van der Maarel 1993). Distinguishing the different types of disturbances is therefore a critical issue of ecology, conservation biology and wildlife management (Soulé and Orians 2001).

Traditionally, disturbances have been considered to be irregular and uncommon events that cause abrupt changes in the structure of populations and biological communities, bringing them away from relatively stable conditions, and close to a potential "equilibrium". Initially, the disturbance was considered to be *an uncommon and irregular event, which causes structural changes in natural communities that are positioned in chemical, physical or ecological conditions different from those that characterized the community before the event (in a hypothetical equilibrium*) (White 1979).

This definition, however, appeared immediately incomplete for a number of reasons. First of all, its strict determinism has proved inadequate as a reference paradigm for complex environmental systems characterized by a different degree of predictability. In addition, few biological communities persist in equilibrium or in its proximity, and it is extremely difficult to assess the presence of such conditions. Finally, the 'change', mentioned in the definition, can be highly variable, ranging from negligible to extreme, and is related to both the intensity of the disturbance

C. Battisti et al., *An Introduction to Disturbance Ecology*,
Environmental Science and Engineering, DOI 10.1007/978-3-319-32476-0_2

and the intrinsic sensitivity of the impacted environmental components (organisms, populations, communities, ecosystems). Each organism (or group of organisms), in fact, shows specific ecological traits that make it more sensitive to certain disturbances than others (home range amplitude, sociability, niche breadth, body size, sex, age, etc.; Isaac and Cowlishaw 2004).

The changes of the chemical, physical, biological, and ecological conditions of a site or of an environmental component may: (i) be observed within a range of variability, (ii) be periodic or occasional or, (iii) occur by a progressive continuum (gradients of variation) or abrupt leaps (thresholds). The problem of defining what is the degree of change that can be termed as a "disturbance", along a continuum of events ranging from negligible to extreme, is therefore posed. The definition of an intensity threshold or frequency beyond which the same event can be defined as disturbance is a difficult and often arbitrary operation. In this regard, the convention that a disturbance is an event 'near to one end' of the range of variation of natural disturbances can be adopted.

Other definitions have also been proposed. According to some authors (White 1979; Pickett and White 1985; Sousa 1984), *a disturbance is a physical, chemical or biological event, with a different frequency degree, causing an alteration or a damage to one or more individuals and that directly or indirectly creates an opportunity for other individuals. This event is able to move the community towards an unstable state of non-equilibrium*. Here, these authors focus their attention only on the level of individuals.

A broader and widely accepted definition (see also Krebs 2001), is the one given by White and Pickett (1985): a disturbance is *any relative discrete event in time (and space) that disrupts ecosystem, community, or population structures and changes resources, substrate availability, or physical environment.*

According to a different interpretation, Grime (1979) has succinctly defined the disturbance as *an event that removes or damages biomasses*. And, again, according to Petraitis et al. (1989), a disturbance is *any ecological and bio-geographical process that alters the rates of birth, mortality, and survival of a population present in an environmental patch through the direct elimination of individuals or affecting resources, rates of predation and competition. Moreover, a disturbance can be considered as any change of structure in an environmental component (populations, communities, ecosystems) caused by factors external to the hierarchical level of interest.*

In an all-encompassing view, a disturbance may still be defined as *a biotic or abiotic, natural or man-made process that can destabilize the natural systems at any hierarchical level* (see Hobbs and Huenneke 1992).

According to another definition, a disturbance *is an ecological process able to determine the formation of environmental mosaics with different successional stage, structuring patterns of environmental heterogeneity, increasing the β-diversity and species turnover among sites or different patches* (Brawn et al. 2001). Such definition, shows interesting implications at landscape scale and on meta-population dynamics for all those species that are spatially structured.

For Collins and Glenn (1997) the disturbance *is an event that causes extinctions at a local scale (e.g., in an environmental patch*) and its intensity can be indirectly evaluated through the measurement of the number of extinct species in a particular *patch*.

According to Sommer et al. (1993), a *disturbance consists of (or causes) any fluctuation in the availability of resources*. This definition differs from the others because it implies that not only the discrete changes (through clear-cut thresholds) but also the continuous changes along gradients may be considered disturbance events (see e.g., the seasonal fluctuations or annual cycles of environmental factors and resources).

A universal definition of the concept of disturbance should (Pickett et al. 1989): (1) identify its target, that is, the affected environmental component at a defined ecological level: individual, population, community, ecosystem, etc.; (2) distinguish between changes induced by the disturbance and those due to other limiting factors or processes (for example, internal to the reference level); (3) distinguish between direct and indirect consequences of the disturbance.

The action of a disturbance leads to the definition of a disturbed area (at a given spatiotemporal scale). Its correct detection is required to implement objectives and actions (Myster 2003).

These disturbances can be described using different criteria. They can be divided, for example, in *direct* disturbances, which directly influence an environmental target component (for example, the probability of survival of the individuals of a species, the density of a population, the richness of species in a community), and *indirect* disturbances, that affect specific ecological targets through other environmental components (Pickett and Thompson 1978; Hobbs and Huenneke 1992).

The disturbances can be divided into two groups: those that act in a *selective manner*, for example causing mortality in individuals of a specific target (the population of a species, communities, etc.), and those that, on the contrary, intervene *randomly* manifesting indiscriminately on the entire ecosystem. The first help to maintain high species richness and diversity of a community; the latter tend to simplify environmental systems, continually altering the structure and composition and keeping them far from a state of a hypothetical “equilibrium” (Petraitis et al. 1989).

Even the scale of reference (absolute or relative) can be used as a classification criterion. In particular, if a disturbance occurs as an exceptionality, causing irreversible impacts at a spatial scale greater than the one it was experienced, it can be defined as *catastrophic*; otherwise, it can be defined as a proper *disturbance*.

In addition, the degree of predictability (and thus the *risk of occurrence*) of an event is useful to define and classify a disturbance. There may be cyclic, periodic, and predictable disturbances or irregular and unpredictable ones. Some environmental changes, such as daily cycles (circadian) of light, temperature and humidity but also seasonal climatic cycles, are events able to initiate significant changes in the environment for many organisms. At the same time, a wide range of irregular events may overlap with periodic cycles resulting in an often complex framework.

One of the priorities for the management of an area or of a specific target of conservation is therefore to investigate the scheme of local disturbances. Such evaluation should be conducted for a given site and at a specific spatial and temporal scale of reference and take into account both the natural and anthropogenic disturbances as well as the direct and indirect effects and impacts on the biological diversity, the environmental mosaic, and the other ecosystem components (soil, water, air, etc.).

Impact, Disturbance, Stress: A Population Ecology-Based Terminology

In ecological literature, disturbance, stress, and impact are often considered as related words. They are frequently and mistakenly used as synonyms (disturbance, in particular, is the most misconceived term) and the definitions available in literature are often poorly understood.

Some of the most debated questions of ecological science revolve around the implicitly contradictory definitions of such term. Only the four principal definitions of disturbance, available in general and plant ecology will be discussed in this section. Other definitions, pertaining to applied ecology, have been extensively treated elsewhere in this book.

Grime (1979) distinguished between disturbance and stress. According to his definition, *disturbance* is the total or partial disruption of biomass whereas *stress* is a decrease of biomass growth rate. Grazing and treading by livestock and wild animals cause disturbance, even though such kind of phenomena are predictable and relatively constant. Hurricanes and landslides are also disturbances although highly unpredictable.

Aridity or the presence of toxic substances, inducing a decrease in growth rate are instead considered as stress. Although Grime's definition is very effective when applied to modular organisms such as plants and corals which accumulate biomass, it proves less compelling when dealing with other kinds of nonmodular organisms.

Grime's definition offers a clear distinction between disturbance and stress, which although separate processes, are often confused. As already mentioned it only suffers from the limitation of being inapplicable to organisms other than plants. However, if instead of considering the nature of the different interferences occurring in a community or a population, we focus on the effects exerted by such interferences on species, Grime's definition can be generalized and applied to nonmodular organisms.

As a starting point, let us consider the population growth curve. When resource availability is constant, initially the curve follows an exponential trend but then it slows down until it reaches a steady state.

If the population is decimated by diseases, catastrophic events or other factors after having reached the steady state, it can go back to the initial phase of exponential growth. Disturbance is therefore a factor by which populations can be maintained in the phase of exponential growth, without reaching the steady state. The departure from steady state conditions does not necessarily occur when disturbance is irregular. Indeed, some populations are adapted to regular disturbance and are constantly kept in a state of exponential growth: for example, the small pleustophytes like those belonging to the genus *Lemna*, whose populations are continuously destroyed by the alterations of water levels in the canals and rivers where they usually thrive, or many species in urban environments. The implications of disturbance for population dynamics have been extensively studied in the case of phytoplankton (Crowley 1975; Sommer 1985), but other common examples are offered by density-dependent species.

To summarize: *disturbance is an interference by which populations and communities depart from a steady state and enter an exponential growth rate. Stress is not a factor which deviates populations and communities from the steady state; rather, it decreases their growth rate. Disturbance can be regular or irregular, natural or anthropogenic. When irregular, it can be defined as a perturbation. Both disturbance and stress are included in the term interference*.

Here follows a presentation of such definitions in the form of a dichotomous key (Ryikiel 1985): *interference* (or *pressure*); a factor which affects populations and communities and can be identified on the basis of their responses:

– it does not deviate populations and communities from the steady state: → *stress*. For example, a pollutant which decreases growth rate (chemical stress).
– it deviates populations and communities from the steady state: → *disturbance*. For example, noise annoyance caused by vehicles passing by on a road located near the nesting site of a stenoecious species capable of hampering its reproductive success and favoring more generalist species (in this case it is an anthropogenic disturbance).
  - it is predictable → *impact*. For example, grazing exerts an impact on grass biomass.
  - it is unpredictable → *perturbation*. For example, a hurricane.

It should be stressed that the same external factor can be classified in different ways, according to how population and community respond.

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Chapter 3
Role and Effects of Disturbances in Natural Systems

Disturbances constitute a complex set of events that play a very important role in the structure and functioning of environmental systems. They induce a change in their state and cause a large portion of the temporal variability and spatial heterogeneity that can be observed at different scales and grains of definition (Whittaker 1965, 1972; Wiens 1989; Hobbs and Huenneke 1992; Myster 2003). These perturbative events affect the amount and distribution of many physical, chemical, and biological factors. Some of them may be limiting factors (space, light, nutrients)[1] inducing an alteration of available resources and a consequent destabilization of the ecological successions.

Disturbances can therefore be considered as important *agents of natural selection*. They play a vital role in determining the composition, structure, distribution, medium-short-term dynamics, and the long-term evolution of animal and plant populations (Sousa 1984; Davis and Moritz 2001; Blumstein et al. 2005). At community and ecosystem level, many ecological processes (such as primary and secondary production, the accumulation of biomass, energy flow, cycles of nutrients) can be changed by the disturbance events. Even many properties of environmental systems such as *vulnerability*, *fragility, integrity,* and *resilience* may be markedly affected by such events. The action of the disturbance affects the overall diversity in environmental systems, overlapping the factors and processes intrinsic to the individual species and their biological interactions (e.g., competitive exclusion).

[1]The species are limited in their abundance and distribution, by geographical factors (e.g. oceans and lands), physico-chemical and climatic factors (e.g., temperature, rainfall, salinity), and the presence of other species they relate with (prey, predators, competitors, parasites, mutualists). Living organisms are spatially placed within well defined geographical regions in which the environmental factors (especially those defined as limiting) are located within their tolerance range.

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The disturbances thus constitute *a form of environmental variability*, discrete in time and space. They allow the transfer of biological material between systems and can cause an unusual mortality in certain biological populations of a site, removing or, at the opposite, making available new trophic resources (Grime 1979). The disappearance or the accumulation of resources and opportunities for other organisms, can lead to a structural and functional change in the ecosystems influencing both the biological components and the physico-chemical conditions (e.g., the amount of light or the content of water and nutrients in the soil; Myster 2003).

The compositional, structural, and functional changes that occur in the biological communities subjected to the action of disturbances are a matter of great importance for both the basic ecological aspect and its implications for biodiversity conservation.

The majority of environmental systems undergo multiple disturbances, both natural and human-induced (anthropogenic), whose effects may be additive or synergistic in increasing or reducing the overall biological diversity (Hobbs and Huenneke 1992). In particular, at the level of the entire communities of animals and plants, the effects of a disturbance event can be observed in the variation of the number of species, the distribution of the number of individuals among them and the overall diversity (variations quantifiable, respectively, through species richness, evenness and diversity indices; Dornelas et al. 2011).

Simplification of Communities Following a Disturbance

Disturbance events may simplify the diversity of specific communities, reducing the number of species and their relative abundances. In particular, the *redundancy* within the communities and ecosystems can be reduced, through the disappearance of species that perform similar roles and functions. All this can make the systems themselves more unstable and vulnerable with implications on their ability to withstand further disruptions (reduction of *resistance*) and to recover (reduction of *resilience*). For example, due to some disturbance events, an environmental system may be more susceptible to be invaded and colonized by opportunistic and synanthropic species, both indigenous and non-indigenous, due to both the general simplification of the environment and the reduced competitive ability (and *fitness*) of the surviving organisms after the disturbance-induced stress (Hobbs and Huenneke 1992; Pickett and Thompson 1978; Fig. 3.1).

The occurrence of an event of disturbance can also lead the communities to be simplified in terms of *phylogenetic complexity* (Helmus et al. 2010). This is due to the fact that phylogenetically related species (that is, with a common evolutionary history and little difference in genetic characterization) show, in general, also a similar sensitivity to certain types of disturbance. The action of a perturbation event can then lead to the disappearance of entire groups of related species, not only in terms of numeric simplification but also of genetic diversity.

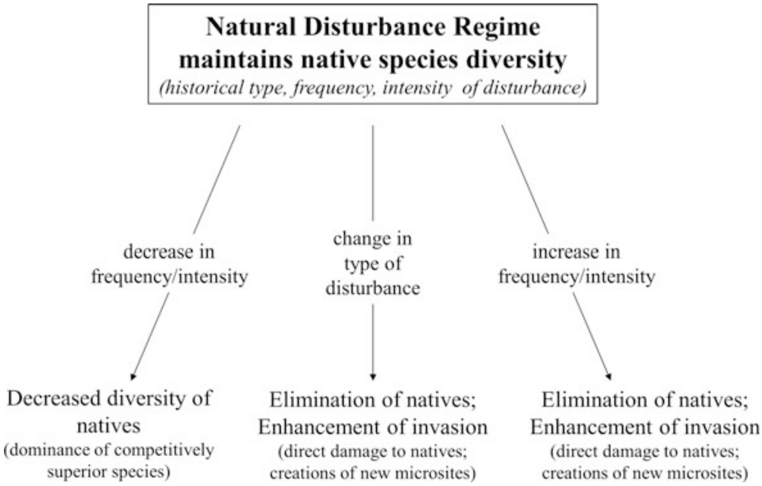

Fig. 3.1 A flowchart synthesizing as natural disturbance regime maintains native species diversity (from Hobbs and Huenneke 1992)

Enrichment of Communities as a Result of a Disturbance

Under certain conditions, some communities may, at the opposite, increase their structural and functional diversity following a disturbance. This can happen as the opportunistic species, attracted by the new food sources made available by the disturbance itself (for example, dead organisms), are greater in number than those disappeared. The degree of change in both the number of species (richness) and in their mutual relations and density of frequency (evenness) depends heavily on the regime of the disturbance, i.e., on its characteristics in terms of frequency, duration, intensity, and surface extension.[2]

The maintenance of a high diversity of species in a community as a result of a disturbance can be determined mainly by either a direct or an indirect mechanism.

The first mechanism (direct), defined as *compensatory mortality*, is when the disturbance causes a high mortality rate among individuals of some species of the community, in particular those defined as dominant.[3] As a result of this decrease in

[2]Among the many examples, one can mention fires and some extreme weather events that constitute a natural disturbance able to increase the diversity of herbaceous species, causing an increase of suitability of soil, space and light. As the diversity of some groups of vertebrates is related, at least in general terms, to the diversity of herbaceous species, the effects are observable even at higher trophic levels. The magnitude of this change will be a function of the regimen characteristics (Crandall et al. 2003).

[3]In a community a species is defined as dominant when it shows a relatively high frequency (expressed on the basis of the number of individuals, biomass, volume, or the coverage on the total community). There are conventional thresholds that define a dominant species.

abundance and frequency of the dominant species, which are more competitive in stable environments but are rapidly selected in unstable environments, an increase in the frequency of previously less frequent (subdominant) species can occur as they are less competitive but more adaptable to ephemeral and dynamic situations. These latter opportunistically exploit the new resources made available by the disturbance and help to enrich the community.[4]

The second mechanism is indirect, and predicts that the increase of the diversity of a community subjected to a disturbance is induced by a general increase in the degree of environmental heterogeneity of a site due to the alteration of the physico-chemical and biological conditions that occur following the event. This increased heterogeneity makes the coexistence of several species possible. As each of them has a different ecology and behavior (e.g., competitive capacity), they structure a more diversified community, as compared to the state prior to the occurrence of the disturbance.

In both cases, following a disturbance, the dominant and very competitive species, will decrease in density because they will occupy unstable and stressed environments, less suitable than those where they can exert a dominance function. On the contrary, the less competitive but more adaptable species can opportunistically exploit the new resources, implementing evolutionary strategies developed in ephemeral and dynamic environments (e.g., exponential demographic growth).

The increase in the number of species within a community, may be monitored when intermediate levels of intensity and frequency of the perturbation occur. In these conditions, there is a coexistence of dominant and competitive species typical of stable environments, with opportunistic and disturbance-tolerant species (*theory of the intermediate disturbance*; Wilson 1994; Collins and Glenn 1997; Crandall et al. 2003; Roxburgh et al. 2004). Higher levels of intensity and frequency of the disturbance can lead in fact to the local disappearance of some of the most sensitive species, while relatively lower levels can favor the most dominant and competitive species at the expense of potential colonizers. In both cases, a decrease of the total number of species in the community can occur.

The conditions for the coexistence of multiple species in intermediate states of disturbance are particularly evident at the scale of territorial systems with a considerable extension (for example, at landscape scale). At this scale of reference, the action distributed in time and space of certain events can lead to the structuring of heterogeneous environmental *mosaics*, whose basic unit, the *patch*, undergoes the action of different types of disturbances at different degree of intensity, duration and

[4]In general, as a result of a disturbance, the total abundance of individuals of all species in the community tends to decrease, although the relative abundance of some generalist and opportunistic species may increase. Therefore, also the total abundance of individuals in a community or in a site can be considered a parameter that can indicate the impact of a disturbance (or the induced change of state).

frequency. As a result, the populations of those species that are resistant to certain perturbation events can coexist with the populations of species that, on the contrary, are more sensitive. The latter will be present only in *patches* where the events did not occur or occurred at a low intensity, duration and frequency (Roxburgh et al. 2004). In these fragments, populations of sensitive species that will potentially recolonize the adjacent disturbed *patches* will establish.

Landscapes subjected to disturbances different in types and regimens will be characterized by a high degree of environmental heterogeneity and, therefore, of biological diversity. The total number of housed species (γ-diversity) and their replacement rate (*turnover*) among *patches* (β-diversity) will therefore be higher than the one measured in areas less disturbed and therefore less heterogeneous (Sousa 1984).

Effects of Disturbances and Responses of Organisms

In the analysis of the internal dynamics of an environmental system it is necessary to distinguish between what is the *effect* of a disturbance on an environmental component and what is the active *response* of the environmental component to the disturbance.

The effects of disturbances on a community may occur and be detected over a long period of time. Some are direct and immediately apparent (*primary* disturbances), while others are indirect and deferred in time (*secondary* disturbances). For example, a fire in a forest can cause a direct and immediate effect that is easy to describe and quantify through the effects on trees and shrubs: a high mortality rate, deterioration and stress on plants. In the long term, however, the disturbance may determine, indirectly, population explosions of opportunistic species (such as in many groups of invertebrates) that colonize the disturbed area due to the high availability of dead and decaying wood (indirect effect). This may have further implications (e.g., ripple effects) on changes in the demographic structure of many species of vertebrates that use invertebrates as a trophic resource (for example, many birds, reptiles, and insectivore mammals).

The effects of environmental disturbances on a system are strongly dependent on the sensitivity of the organisms. This, in addition to be an intrinsic attribute of each species as dependent on its ecology and its evolutionary history (Martorell and Peters 2009), is also a characteristic of each individual (intraspecific individual level). In fact, biological organisms that differ in age, size, sex, behavior, and physiological state (fitness) may be differently sensitive to a particular event of disturbance while belonging to the same species.

A disturbance acts on an organism through a *pressure* that determines a *change of state*, and therefore an *impact* on it. The impact can be measured in terms of *metabolic cost*. The *metabolic cost* is due to the mechanism of homeostatic response that organisms adopt in stressful conditions (e.g., acclimatization, regulation, etc.) in order to restore the internal balance following the environmental changes that were induced by the external perturbation. Such responses imply an energy cost. Many species can modulate the excretion of a stress hormone as a response to the presence of a disturbance. However, response, regulation, and adaptation mechanisms become impossible beyond a certain threshold (*allostatic overload*; Arlettaz et al. 2009). Therefore, with the increase in the level of stress, the organism can become more sensitive to other disturbances, reducing its *fitness* and ranges of tolerance towards other limiting factors.

Organisms have a wide range of response devices as well as morphological and functional regulations that allow them to adapt to different environmental conditions while maintaining or increasing their *fitness*. In relation to the *response time*, depending on the type and regime of the disturbance and the characteristics of the disturbed organism, both eco-physiological (short-term) adaptive responses and evolutionary (long term) adaptive responses can be identified.

More specifically, four types of adaptive responses to external perturbations can be found. The first three are non-evolutionary (physioecological):

– *Responses of regulation*: they involve reversible, physiological, and behavioral changes that increase or reduce the speed of various processes (e.g., body heat regulation); even the cultural changes in certain populations as a result of disturbances fall within these response mechanisms that may also be inheritable by unrelated subjects;
– *Responses of acclimation*: they imply morphological changes (e.g., thickening of fur, proliferation of red blood cells, epidermal pigment production). They are reversible structural changes that require more time to be realized with respect to the previous regulation responses;
– *Responses of development*: these are permanent and irreversible responses to the environment that take a long time to manifest, at least at the time scale of the individual lifetime. Such responses are structured progressively during the period of development of the organism.
– *Evolutionary responses*: they occur over long times and over many generations. There are no responses at the individual level but occur at the level of the entire genetic *pool* of the population.

The adaptive responses of non-evolutionary kind may precede the development of specific adaptations in populations (for example, when the latter undergo selective changes in the environment or move actively in different geographic areas).

The adaptive responses use a variety of feedback mechanisms of negative type (*negative feedbacks*). Basically, if particular features or components of an organism suffer, as a result of disturbances or changes that set them apart from a desired state, the organism itself acts to reverse this shift, returning to a state of normality (stabilizing effect).

The response modalities also depends on the speed of environmental changes, the duration of the biological processes of the organisms (e.g., physiological mechanisms), and their longevity.

The response of organisms to disturbances also depends on the observed scale of reference. At continental and global scale, species can be distributed in response to factors such as seasonality, rainfall, and temperatures along geographical gradients (e.g., latitude). At regional scale, organisms can respond to topographic and geomorphological factors that overlap climate factors. Finally, at local scale, physical, chemical, and biological factors can be crucial. This is the scale of most of the natural and anthropogenic disturbances discussed in this volume.

Biological organisms can respond to disturbance events evolving, over time, mechanisms of coping that change the cause-effect relationship between the disturbance and the environmental component. A specific disturbance may alter in the short-term both mortality and reproductive success in a given population, leading to long-term, evolutionary response, with a selection of genotypes more resistant to the process of disturbance. Therefore, over time the population will show a different sensitivity to the event: a fluctuation or an environmental perturbation that have been perceived as a disturbance by a population in the past may no longer be perceived as such in the future, thanks to an evolutionary adaptation (e.g., Bond 1998).

The dynamic and evolutionary relationship between organisms and perturbation events are particularly evident when analyzing the responses of many species to periodical changes. Biological organisms must be able to predict environmental changes. One of the best known examples is the change in day length as an indicator of seasonal change. In this sense, the periodic variation of some seasonal environment parameters have been acquired by many species as a useful opportunity to complete the life cycle, growth, reproduction, and dispersal dynamics (consider the changes in water levels in the Mediterranean wetlands following summer aridity and the evolutionary responses of hygrophilous vegetation, many invertebrates, migratory birds, and amphibians).

The dynamic relationship between the disturbance event and the organism response can transform the event itself in a evolutionary opportunity, emphasizing the link between the effect of a disturbance and the response to it. However, organisms cannot evolve adaptive responses to disturbance events occurring at time intervals longer than their biological cycle (Sousa 1984).

Following a disturbance, an environment can be perceived less suitable for certain species, even in the presence of spatial or trophic resources. Among the many examples, we can mention some studies that show a removal of some bird species from optimal habitats (in terms of presence of resources) due to road traffic disturbance (noise pollution) that limits communication between individuals and increases the physiological stress. Individuals of these species are forced to move to less suitable areas where they concentrate in higher densities, with implications for their ecology, physiology and behavior. Some recurring disturbances with a predictable frequency (e.g., induced by uncontrolled attendance and noise in sensitive areas) may lead to an adaptation (*habituation*) as a response mechanism (Gosling and Sutherland 2000).

At the level of most species forming a community, the relationship among disturbance, effect, and response may depend on the kind of impact that the disturbance causes on the entire system. A perturbation event, in fact, can cause a selective mortality in individuals belonging to certain sensitive species (disturbance effect): as a consequence, a turnover of species in the community can occur (response to disturbance; see what mentioned earlier about the *compensatory mortality mechanisms*; Bhattacharjee et al. 2007). The selective herbivory found in many species of mammals that turn their trophic activity on a few plant species only, for example, helps to maintain a high diversity of species in some plant communities of grassland (example of system response). On the contrary, a disturbance can cause a *catastrophic mortality*, intervening randomly over most of the individuals belonging to the species present in a community. In this case, a structural simplification of the system that prevents the achievement of a state of equilibrium can be observed (that is, a stability condition in which the internal mechanisms of competition are crucial in predicting species composition; Petraitis et al. 1989). Examples of disturbances with a catastrophic effect on the communities are some natural events that occur on medium to large scale. This is the case of floods as well as many volcanism-related events and other geological phenomena (tectonic or seismic) which affect in a non-selective and random manner both plant and animal communities, regardless of their specific composition and the stage reached within the succession. Although infrequent, these catastrophic events may exert a particular impact on biological communities, causing consequences in the long term.

The effects of disturbances and the organisms' responses may not increase linearly with the characteristics of the disturbance regimen (such as the extension, frequency, or duration of the event). Some authors (e.g., Romme et al. 1998) have distinguished three classes of responses: (i) *continuous* responses, where one can observe a linear relationship between the magnitude of the characteristics of the regime and the responses of the system; (ii) *threshold* responses, in which the responses are obvious only after exceeding a threshold value related to one of the characteristics; and (iii) *independent* responses, which are not related to changes in the values of the characteristics of the regime.

In conservation biology, there are some statistical techniques that analytically investigate the responses of the species to specific disturbances, such as through the variation of density in one or more populations: e.g., the *disturbance-response analysis* by Martorell and Peters (2009). These authors define three categories of species on the basis of the relationship between the intensity of a disturbance and the response of the population through the variation of its density: (i) *vulnerable* species: their density decrease monotonically with increasing intensity; (ii) *resistant* species: their density does not change with the change of intensity; (iii) *favored* species: they monotonically increase their density as a result of the increase in intensity. This is a basic model, and obviously intermediate or different responses by many other species may exist (e.g., species that react with a ‘bell-shaped’ curve or in a multimodal manner to variations in intensity of the disturbance). These authors point out, however, that the responses of the species (in particular of plants) to variations in the intensity of a disturbance can become more complex because of the overlapping with climatic, edaphic, and topographic factors.

Effects and Different Responses Among Sessile[5] and Vagile[6] Organisms

The effects and responses that organisms undergo and adopt towards the disturbance events differ greatly in relation to some biological, ecological, and behavioral characteristics of the organisms. A first criterion of distinction can be adopted distinguishing *sessile* organisms from those with different degrees of *vagility*.

Regarding sessile organisms, disturbances due to the physical and mechanical agents, may lead, especially if recurrent in time, to their temporary or definitive disappearance from many sites. If such disturbances act unevenly on areas of significant extension (e.g., at landscape scale) heterogeneous environmental mosaics can develop, with alternating *patches* at different stages (or scheme) of manifestation of the disturbance. The *patches* will differ among themselves for composition and structure depending on the presence, type, and regime of the disturbance as well as the proportion of present sessile organisms. The minimum spatial unit within which the environmental mosaics are characterized by this type of heterogeneity is also defined as *minimum dynamic areas* (MDA; Sousa 1984).

In areas subjected to intense disturbance with little or no selectivity, such as a fires or some geological, meteoric or extreme anthropogenic events, the community of sessile species or with a low dispersive capacity (e.g., invertebrates and small vertebrates) can be heavily altered, resulting in the disappearance of individuals, propagules, and entire populations. Their disappearance may have very pronounced effects on other groups of animals and plants and the entire environmental system. In fact, the sessile species often influence (at short, medium, and long term), many

[5]Sessile animals, are all those organisms, often aquatic, incapable of movement and living anchored to a solid substrate such as rocks, boat hulls, plants, algae or other animals. Generally, the larval stage of these organisms are able to move, in order to colonize new environments. This term is also used more broadly to refer to all biological organisms characterized by little or no ability to move.

[6]This term refers to all those organisms capable of movement, not fixed to a substrate.

Fig. 3.2 Vegetation response to fire disturbance. Here, a "crown" pattern around a burnt shrub of *Ampelodesma mauretanicus* (*Photo* Corrado Battisti and Anna Guidi)

physicochemical parameters of the environment and climate, as well as the structural complexity of the site and the quality and quantity of available resources.

Once the disturbance event terminates, a process of recolonization may start. The speed of recolonization depends on the dispersive capacity of seeds and propagules of the different species and the proximity of the *source* populations. This dispersion process is crucial and is the basis of the meta-population dynamics (also called *between-patch* dynamics, which can occur among both sessile and vagile organisms; Sousa 1984; Hanski 1998; for burnt areas see Fig. 3.2).

Vagile organisms vary greatly in eco-behavioral skills to react to events. For example, in birds, a highly vagile group, disturbances in general affect their presence, abundance, distribution and behavior (Burton 2007). Following a perturbation event, vagile individuals that are sensitive to disturbance may reduce the risk of local disappearance actively moving toward less disturbed sites and/or with more resources. Temporarily, they may even exploit the same resources made available by the perturbative event (e.g., for direct mortality of sessile organisms: consider dead or dying plants after a flood event or a fire and the resulting saproxylic insect and bird opportunism that exploit the food and the space made available). Many species characterized by a high vagility prefer to colonize the intermediate stages of the vegetation succession, as in a recently perturbed *patch*, due to the greater availability of resources (e.g., due to the higher richness and abundance of prey species). In areas subjected to grazing, quality and palatability of many plant species are often higher in the initial and intermediate stages of succession.

The direct effects of disturbances on vagile species are not easy to detect. In addition, in these species, it may be difficult to associate the action of certain events with the effects they cause on populations and communities because of a delay (*lag*) between the occurrence of the event and the response of the organisms. This is mostly evident in those species which are characterized by a high mobility (e.g., insects, bats, birds).

Interaction Among Disturbances

Disturbances can interact among each other in a complex and non-linear way. They can either increase or reduce the likelihood that other events, different in type and regime, can occur. In addition, some disturbances may be synergistic, that is, have overall effects not only additive but also multiplicative on the environmental components. Disturbances that overlap temporally or spatially may induce persistent and irreversible effects, especially if they occur with frequencies higher than the normal recovery processes of the environmental systems (Davis and Moritz 2001).

Effects of Disturbances on Biological Communities: Approaches and Metrics

Natural and anthropogenic disturbances affect biological communities by making resource availability more variable, thus causing a reorganization of species coexistence patterns. As a consequence of specific disturbance events, structure, and composition of biological communities undergo alterations which are measurable. Such quantification turns out to be useful when studying both the ecological effects/responses showed by communities following the disturbance events, and when developing management and conservation strategies of specific sites.

Disturbance-induced changes in biological systems are detectable at all hierarchical levels (from individuals to ecosystems and beyond). In this section, some approaches and metrics useful to quantify the effects of disturbances on the community hierarchical level will be reviewed, summarizing the recent contributions of other authors (see Magurran 2004; the review by Dornelas et al. 2011).

As far as the community level is concerned, usually more than one metric[7] is utilized to quantify the effects of a disturbance. This is due to the fact that disturbance and biological diversity are complex concepts, containing much information, which can be made explicit only utilizing different metrics. Using few variables or indices hampers the interpretation of natural system diversity and makes it impossible to obtain the 'magic number' which allows us to gain extensive information (see Battisti and Contoli 2011). The appropriate metric to be utilized depends both on the type of disturbance and on the type of the effects we want to assess. For example, we may be interested in the analysis of the effects induced by a disturbance on all the species of a given community, or, alternatively, of those affecting only a few of them (for example, the rare or the dominant species).

To quantify the disturbance-induced effects on communities, three categories of metrics are available, which can be grouped according to a progressive increase in the information they contain: (i) univariate metrics; (ii) abundance distribution-based metrics; and (iii) multivariate metrics.

Univariate metrics—They allow us to synthesize in one number the information associated with a biological community. They quantify:

- *Species richness*. To quantify species richness (aka normalized number of species) in a biological community, numerous metrics are available. They are the simplest but also the least informative, at least when it comes to the analysis of the disturbance-induced effects on communities. Metrics associated with the mere number of species show a low degree of reliability, for several reasons: (i) species richness in a site will decrease (often in a very limited way) only when the regime attributes reach high levels (for example, high intensity or frequency of disturbance). In many cases, the richness parameter may turn out to be unaffected by such events, at least in the short term and at the scale of the sites under study; (ii) the relation between species richness and certain regime variables (e.g., intensity and frequency) is hump-shaped, i.e., it often reaches the highest levels when the disturbance attribute under consideration shows intermediate conditions (e.g. intermediate levels of disturbance frequency or intensity relate to the maximum value of species richness; compare the Intermediate Disturbance Hypothesis); (iii) finally, since species richness is strictly related to the area (Preston 1960; MacArthur and Wilson 1963, 1967), the results obtained by comparing the richness values belonging to disturbed areas of different size are not easily interpretable;
- *Evenness*. It expresses the degree of abundance (or relative frequency) repartition among the species present in a community (i.e. the relative asymmetry among the species' relative abundance/frequency). Such a metric is very

[7]Metric is a variable or an index which can be quantified with an appropriate unity of measurement.

sensitive to disturbance events: i.e., the species' relative abundance/frequency (and thus the evenness values) can undergo dramatic changes following a disturbance event. Evenness can be represented by different indexes (compare Magurran 2004; Magurran and McGill 2011).

- *Species diversity*. These metrics combine richness and evenness in one value. Also in this case a great number of indexes exist (Simpson, Shannon-Wiener, Berger-Parker) which differ in the sensitivity degree to the number of species or to the number of rare species. Moreover, they differ in the emphasis given to one or the other diversity components (richness and evenness) in the overall evaluation. In this respect it is important to carefully evaluate the type of information provided by such indexes, just because they reflect the relative weight of the two components, which are also complementary.

Abundance distribution-based metrics or *SADs Species Abundance Distributions*.—These metrics comprise a series of non-parametric measures based on abundance distribution or on the distribution of other species traits (such as biomass and cover). They are:

- Relative slope and shape of rank-relative abundance distributions or dominance-diversity distributions. In the approach based on dominance-diversity curves (Whittaker 1965), the impact of specific disturbances can be traced back observing species frequency distribution in a community, particularly through the analysis of the shape of species/relative abundance distributions (Rank Abundance Distributions, RADs). In such curves, evenness values are represented in log scale.

In a diagram plotting species ranks (from 1 to n) on the x axis and on the y axis species relative frequencies (obtained from the ratio: abundance of one species/total abundance of all species)[8] a slight slope in the curves indicates high evenness values whereas higher values of this index are expressed by a lower slope (Fig. 3.3). Since, in general, a disturbance affects a community's evenness by decreasing it, the effect of a natural or anthropogenic disturbance on such a system can be detected through the increase of curve slope.

However, it should also be pointed out that curve shape (or slope) is markedly affected by the number of species. Therefore, when comparing disturbance-affected communities, containing very different numbers of species, particular caution must be applied. To overcome this problem, data can be normalized to the number of ranks (which are an expression of the number of species; more in Dornelas et al. 2011).

- *Empiric cumulative distribution function*. It expresses the proportion of species which shows a given abundance in a community. Such proportions can change following a disturbance. This approach is independent of the number of species since the proportions are calculated as relative figures with respect to the total.

[8]The relative frequencies can be transformed into log format.

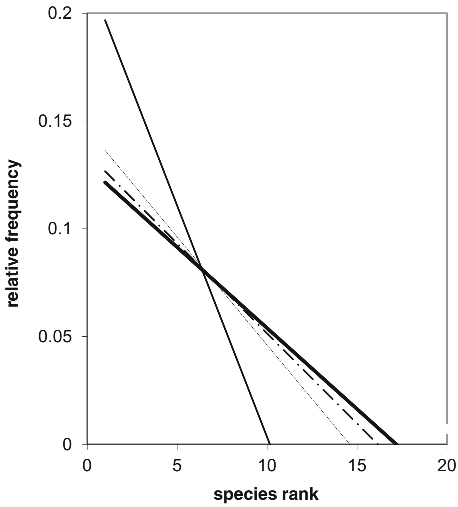

Fig. 3.3 Dominance-diversity diagrams representing communities of breeding birds in four forest fragments of progressively decreasing extent (Latium, central Italy). *Continuous line in bold* Macchia di Gattaceca (>100 ha); *broken line in bold* Macchia Trentani (10–100 ha); *broken line* fragment with a surface of 1–10 ha; *continuous line* fragment with a surface of less than 1 ha (Battisti et al. 2009). Size reduction affects communities as a stress factor inducing a change in evenness, and thus, in curve slope

– *K-dominance plots*. These diagrams show species abundance in a cumulative way. Rank 1 is assigned to the species with the highest relative frequency (or dominance) in the community; in the second rank the sum of the two first more frequent species is reported and so on until the cumulative value is obtained (the asymptote is represented by the value 1 for the relative frequency and 100 % for the percentage frequency). Differently from RAD, in this case, along the *y* axis the cumulative frequency is reported instead of the relative frequency of the individual species. The curves which cumulate first represent the characteristic distributions of disturbed communities when compared to similar communities not affected by perturbations (Fig. 3.4).
– *Abundance-Biomass Comparisons* (ABC). These curves represent a variation of the k-dominance plots and allow us to assess whether a community is impacted without comparing it to a not impacted 'control' community. With such diagrams a comparison can be made, within the same community, between the curves of cumulative relative frequency obtained from individual abundance values and the curves of cumulative relative frequency related to biomass data (individual body weight × total body weight). The differences can be quantified using specific metrics (e.g., the *W* statistics measuring the total distance of each

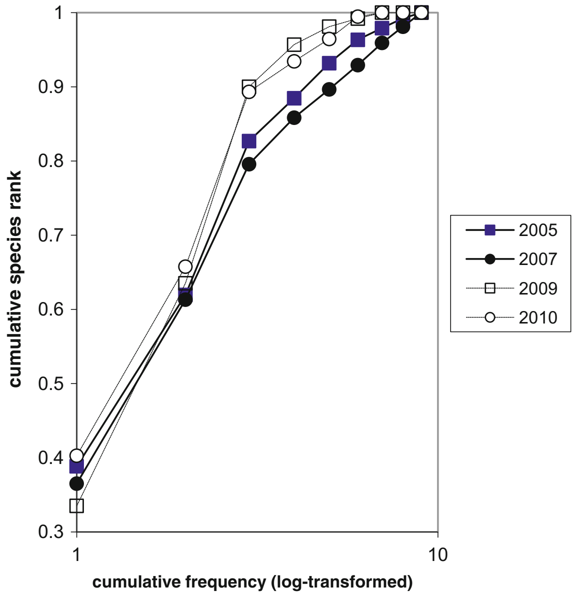

Fig. 3.4 K-dominance diagram for a community of Chiroptera located in an area of the Abruzzi Apennines, where in 2009 a wind farm was implanted (Ferri et al., unpublished data). Each point represents a species with a given cumulative frequency (rank 1 species: frequency of the first dominant species; the subsequent point, immediately to the *right*, represents the cumulative frequency of the first two dominant species and so on). Each *line* represents the community species set for a given year. In this case study, curves cumulate after the wind farm construction, leading to hypothesize an effect of this structure on biological community (either for direct impact of individual bat fatalities at turbines or for direct impact induced by habitat transformation)

curve form the *X* axis,[9] or the *R* metric, measuring the area under the curves; Dornelas et al. 2011; Fig. 3.5).

Models are associated to SADs and they are utilized to explain which kind of point distribution a diagram shows, with implications for the disturbance level of a community (log-series, lognormal, gambin, *Q*-statistics). For example, lognormal distribution is an appropriate description of frequency distributions in undisturbed environments, a geometric series describes communities characterized by high levels of disturbance, whereas a log-series is best fitted to data representing species frequencies in moderately disturbed communities (for more in-depth analysis see Dornelas et al. 2011).

– *Multivariate analyses*. In the previous approaches, metrics were considered which are independent of the species identity (each species was expressed as

[9] W value ranges from −1 to +1: positive values indicate undisturbed communities; negative values refer to disturbed communities (Clarke 1990).

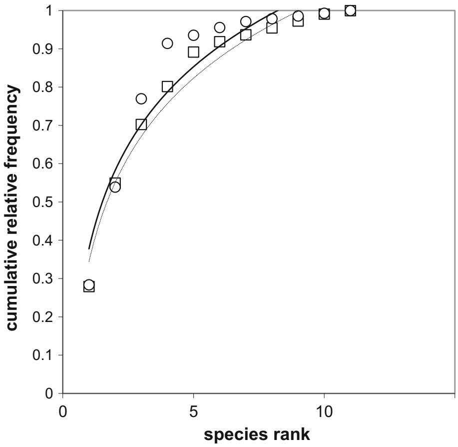

Fig. 3.5 ABC diagram for a community of ground-dwelling micro-mammals (Soricomorpha and Rodents: 11 species, each represented by a circle or a square) preyed upon by a barn owl (Order Strigiformes; species: *Tyto alba*) in the Mount Soratte natural reserve (Latium, central Italy; from Prete et al. 2012). Each point represents a species with a cumulative given frequency (rank 1 species: frequency of the first dominant species; the subsequent point, immediately to the right, represents the cumulative frequency of the first and the second species, i.e., of the first two dominant species, and so on). Squares and broken curve refer to the frequencies calculated on biomass; circles and continuous curve refers to the frequencies calculated on individuals (abundances). Curves largely overlap, and this leads to hypothesize that the assemblage of micro-mammals is not affected by any possible disturbance present in the area

rank, or weight, in the community, calculated independently or in a cumulative way). However, it should be considered that each species differ in its sensitivity to certain disturbance events. Multivariate analysis, allows us to treat individual species (identified by their traits: abundance, biomass etc.) as variables. In such a way, specific differences among them in their sensibility and responses to specific disturbance events can be detected (see Dornelas et al. 2011).

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Chapter 4
The Disturbance Regime

Acts in the ecological theatre are played out
on various scales of space and time.
To understand the drama,
we must view it on appropriate scale

(Wiens 1989)

To thoroughly understand the extent, the spatial and temporal articulation and the action modalities of a disturbance event on one or more particular environmental components present in a site, knowing its specific *regime* is a necessary starting point (White and Pickett 1985).

Disturbance regime encompasses *all the spatial, temporal, physical, ecological characteristics (or attributes*[1]*) and the intensity factor which are necessary to characterize, describe, and quantify a perturbation event*. The knowledge of the real/effective regime of a disturbance is of fundamental importance to research purposes, as well as to the adoption of proper management and conservation strategies.

The characteristics of a disturbance depend both upon intrinsic aspects of the system which undergoes the event and upon factors, processes and local physical, chemical, and biological conditions external to the site. Moreover, such characteristics can vary with time and among different sites (Sousa 1984; Pickett and White 1985; White and Pickett 1985; Hobbs and Huenneke 1992; Brawn et al. 2001; Myster 2003).

Different regimes of the same disturbance can lead to different effects on certain environmental components and in such way constitute as much an impact and stress factor as an ecological or evolutionary opportunity.

The attributes characterizing the disturbance regime (*regime components*) can be grouped in three categories: *spatial* and *temporal* ones and attributes related to *intensity* and *modality*.

[1]Henceforth, to describe a natural disturbance, or an anthropogenic threat, the terms characteristic, attribute or variable will be treated as synonyms.

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Spatial Components

Spatial components include all those attributes which are related to the spatial characteristics of the disturbance event. They can give either qualitative/descriptive information (for example, by enabling the territorial characterization of the event) or quantitative information. The qualitative spatial attributes comprise:

Localization: it gives geographical information pertaining to the area where the event occurs (in terms of latitude, longitude, altitude, toponyms) on the basis of the level of detail (scales and grains) defined by the necessities and the objectives of the researchers who carry out the analysis;
Spatial distribution: it yields absolute or relative information concerning the spatial arrangement of the phenomenon (Wiens 1989). The disturbances can be (i) qualitatively described as localized or distributed across areas of considerable extent (for example, at a regional scale), showing either a uniform or a patchy distribution. The disturbances distributed across wide-ranging areas and being spatially homogeneous have considerable effects on the ecological components leading to a general environmental homogenization; conversely, the localized disturbances with a patchy distribution can augment the diversity at a regional scale (through an increase of β- and γ-diversity determined by the high rate of species turnover among sites and *patches*; Dornelas et al. 2011).

As far as the quantitative spatial components are concerned, the following are instead identified:

– the *scale*: The disturbance effects and the ability of an ecological component to recuperate after an event (i.e., its resilience) are strongly tightened to the absolute or relative spatial scale in which such an event occurs.
– the *extent* (*areal extent*, *spatial extent*, or *size*): It corresponds to the size of the territory affected by the event (for example, disturbed surfaces and volumes calculated according to specific units of measurement). It can be calculated to the scale of a single environmental unit (or *patch*; for instance in the discrete disturbances like the gaps caused in a forest by tree falls) or to a greater scale (for example, to the landscape scale, as the extent of the grazing area for ungulates in a grassland). This attribute can also be considered absolute (disturbance extent) or relative (disturbance extent with respect to the surface occupied by the environmental component which constitutes the reference target; extent per time unit; disturbance extent as a percentage of the total study area; etc.). The same disturbance can distinctively affect different sites or environmental components of different sizes: events of relatively low intensity taking place in sites of reduced dimensions and housing residual plant populations or associations can turn out to be catastrophic. They can lead to the extinction of the local populations and consequently to the irreversible alteration of entire communities (Sutherland 2000). Here are further definitions which can be used according to necessity (Wilson 1994): (1) *disturbance patch*: it constitutes the contiguous (physically not interrupted) area in which the effects of a

disturbance are uniform; (2) *disturbance area*: the total area which is disturbed in a specified instant or period (independently from their uniformity); (3) *sampling area*: the study area (4) *community extent*: the extent of a target biological community significantly affected by the disturbance.

Spatial pattern: it comprises a series of topological or spatial–geometrical parameters, such as the *shape* of the event or of its effects on particular components, the *spatial distribution*, *the closeness to disturbed or undisturbed sites.*[2] All these attributes can be defined both on the scale of the single site (patch) and in larger areas (landscapes, regions). They are important in order to predict the future behavior of an event since they can provide information about the possibility that it impacts or propagates itself, affecting, for example, areas of particular concern or vulnerability. Such attributes can enable to predict potential recolonization processes following the event by animal or plant organisms coming from adjacent patches; for instance if the spatial configuration taken by an event is such that it maintains a connectivity among animal populations, this might imply an easier recolonization process by organisms from adjacent areas (Lindenmayer and Fisher 2006; see the "disturbance mosaics" in Hobbs and Huenneke 1992).

Temporal Components

They include all those attributes referred to the time scale variables.

Among the descriptive ones we can identify:

- the disturbance *history*: the history of the events which took place within an environmental patch or at a larger scale can be important to understand the local composition of biological communities, their structure and functions in a particular site and temporal range of reference (Swetnam et al. 1999; Myster 2003);
- the *seasonality* (or *time*): it defines the period of the year when the event occurs: events of the same duration and frequency can cause diverse effects in different periods of the year.[3]

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[2]Many other spatio-geographic metrics (such as fragmentation levels, connectivity, contiguity, scatteredness) can also be applied, and are available in many software programs (for example FRAGSTAT).

[3]In a Mediterranean wetland, for example, a water stress, considered as a sudden decrease of water level exceptionally occurring in Winter (a period in which such areas are visited by numerous migratory birds), can exert marked effects on the ecosystem. These are extremely different from the effects caused by the same event taking place in Spring or Summer, when many of the sensitive bird species are absent (see Causarano et al. 2009). In fact, in Spring and Summer such ecosystems are frequented by group of water-related species equipped by evolutionary strategies which allow them to perceive the same event as an opportunity.

The temporal components which can be quantified are

- the *frequency* of *occurrence*: the number of times a given disturbance event occurs in a site or territorial area within a predefined temporal unit (for instance a month, a season, a year, a decade). It is distinguished into: (i) random point frequency, or the average number of disturbance events per time unit in a random point of an area (probability or decimal fraction of events per time unit) and (ii) *regional frequency* or the total number of disturbance events per time unit occurring in a given area.
- the frequency can also be inversely calculated through the *turnover rate*, or *rotation period* (aka *turnover time*, *recurrence* or *recurrence interval between events*; Wiens 1989; Davis and Moritz 2001).

Disturbance events frequency may be an important characteristic able to influence individuals' life cycles, the ecology and distribution of populations and of entire species, the structure and dynamics of community and of ecological processes. In this sense, to predict the effects or the reactions of particular organisms to a given event, both the absolute event frequency and the frequency related to the duration of the sensitive species' life cycles must be assessed; *duration* of the event or the *time involved*: it can be either an absolute duration (expressed for example in hours, days, months) or a relative one (when referred to a species' life cycle or to an ecological process).

The *time elapsed from the origin of the event* and the *time elapsed from the temporary or definitive end of it*. The qualitative and quantitative composition and structure of many animal and plant communities change as a function of the time elapsed from the beginning of the disturbance or from its ending (as in the case of the plant succession). Some species require some time from the end of the event before being able to start colonization processes or attain the reproductive phase.

Predictability. It represents a measure of the variance of the average times between disturbance events and it is utilized in the case of recurrent and inconstant (shifting) disturbances: the less the variance the more the predictability will be. Predictability increases as a function of the analysis scale: from local (the typical scale of a disturbance event; at this scale the disturbances generally cannot be constant over time and are random) to regional (the total area within which a disturbance regime occurs; at a regional scale the disturbance events can be more predictable; Davis and Moritz 2001).

Time scaled variables, above all *duration* and *frequency*, are important to distinguish between long time *press disturbances* and short *pulse disturbances* (Bender et al. 1984)[4]

[4]In ecology we can also distinguish between pulse and press processes. The former measure the response of a system following a single treatment/perturbation and its recovery capacity; therefore they constitute an estimate of the system resilience. The latter measure the response following a treatment/perturbation maintained continuously through time (Gotelli and Ellison 2004). For communities this has implications with respect to the attainment of equilibrium conditions.

Magnitude and Modality Components

These attributes indicate the overall intensity of a disturbance and its modalities of occurrence.

– absolute intensity or *intensity*. Absolute quantitative measure of the disturbance (e.g., the overall temperature or energy emitted by a fire, the amount of heavy metals or other chemicals introduced in a water stream) independent from the effects caused on specific environmental components. Such an attribute can be normalized to the extent of the event and/or to the event duration (through the intensity/time or space ratio);
– relative intensity or *severity*. This attribute allows an evaluation of the effects exerted by the event on the target environmental components which have been identified (targeted) as sensitive to the event itself (for example the basal area of a sensitive plant association removed by a given disturbance). It can be normalized to time and space. Relative intensity can be considered a specific impact measurement and it can differ among environmental components, since it depends both on absolute intensity and on species-specific and intraspecific (individual) sensitivity of the organisms. The latter is a function of their biological, ecological, and evolutionary characterization (Collins and Glenn 1997). The scores assigned can be either positive (+, positive severity or opportunity) or negative (−, negative severity).
– *reversibility*. It estimates to what extent the effects caused by a disturbance upon a specific environmental component can be reversed. It depends both on absolute intensity and on the characteristics of the impacted system (relative intensity). Reversibility is also related to the resilience of the environmental system which undergoes the disturbance.
– *synergism*. It is an expression of the synergistic effects of different disturbances which take place approximately at the same time in the same area.
– *specificity* (or *selectivity*). Since events may be more or less selective in presence of a large number of targets, this attribute is an expression of the level of specificity of a disturbance.

  Some disturbances can be of lower specificity when they are indiscriminate and unselective (as in the case of fires), inducing a reframing of the community structure with a reduction of species richness and a shift in species dominance (Ukmar et al. 2006). Others (like pathogens) can be highly specific affecting only one or a few sensitive species. As in the case of many other attributes, disturbance specificity can also be ranked according to specific scores (for example, 1 low selectivity or specificity; 2 medium; 3 high; 4 very high). Although conspicuous effects can be exerted in complex systems by low specificity disturbances, in the same way a community can be dramatically affected by the action of highly specific disturbances. For example, if the sensitive species is relatively abundant/common and each individual shows high body weight, the effects in terms of total biomass are also likely to be relevant at the community level as a whole. The same turns out to be true for those high

specificity disturbances which affect the ecosystem keystone species and induce cascading effects.
- *magnitude*: it yields succinct information about the overall pressure exerted on a component by a disturbance event. Usually, in relation to a specific event, it is obtained as the arithmetic sum of its *extension* and *intensity*, but other approaches can also be considered (for example, the comparative ones).

In order to quantify the entity of a disturbance and to analyze the overall dynamics of a natural system, frequency and intensity are the most employed components because they directly affect composition, diversity and complexity of the system itself.

Species diversity within an environmental patch may turn out to be greater when the intensity and frequency of the disturbance events pressing on it show intermediate values with respect to their *range*. In fact, only a limited number of highly resistant species can persist over the medium-long term in a patch where the disturbances show a high degree of frequency and severity. On the contrary, an equally limited number of them can persist in the opposite conditions, i.e., with no disturbances or when their frequency and intensity are extremely low. Stenoecious species are a good case in point, since they are strictly linked to stable conditions and to the absence of perturbations. Unlike those species adapted either to perturbed and unstable conditions or, conversely, to stable and undisturbed ones, the majority of these show a certain degree of ecological generalism which enables them to persist at intermediate disturbance levels (compare with the Intermediate Disturbance Hypothesis; Connell 1978; Hobbs and Huenneke 1992).

Finally, some attributes of the disturbance regime may interact and their interactions may result in a feedback, catalyzing the overall impacts on the environmental components. For example, an increase in the frequency of specific disturbances may result in an increase in their intensity and consequently in a decreased reversibility of its effects.

Disturbance Regime and Management Strategies

When dealing with management strategies of a naturalistic area an important approach is to characterize the disturbance in a site and to define its regime by establishing the cause and effect relationship between the perturbation event and the environmental components to which it is related.

In environmental systems, naturally occurring disturbances can play a decisive role and maintaining their regime through process-oriented strategies could be considered a major goal (Lindenmayer and Fisher 2006). However, this may be particularly difficult in anthropized contexts where such approach may conflict with the attitudes of the local community and raise political, legal, health, and civil protection issues not easily accepted by the human populations (as in the case of the disturbances caused by fire management and flooding, Mace et al. 1998).

Maintaining or controlling disturbance regimes can become a necessity also when dealing with historic anthropogenic disturbances which have occurred for a long time. This is currently a particular problem for all the reserves where nature conservation is effected using a traditional management approach. According to such view, the major objective is the non-judgmental elimination of every disturbance connected to human activities (following an approach now considered naïve). In a protected area, for example, eliminating or decreasing the grazing activities of domestic cattle without performing an historic analysis of the process (which would highlight its long-lasting existence) can result in further effects and impacts on the environmental components which, over time, have adapted to such conditions. This aspect can be clearly pointed out in those areas, like the Mediterranean region, where human activity, dating back thousands of years, has contributed to landscape shaping (Blondel and Aronson 1999).

Defining the reference regime which may be desirable is an important aspect of process-oriented management (Hobbs and Huenneke 1992). Such definition may not be easy for human-altered landscapes since historical times and the goal to restore the original regime characteristics may prove inadequate to the new conditions which have been established by human activities. In fact, the latter may have built up specific processes and systems which have coadapted to the human presence (for example, agricultural ecosystems).

Therefore, regime attributes and characteristics can be useful to quantify and compare the disturbances, as also extensively reported in the section on anthropogenic disturbances (*threats*, part 2). Two methods can be employed to assign values to such attributes: using specific metrics and unity of measurement (*fine-grained* and analytical approach) or a *coarse-grained approach* with scores allowing immediate estimates and comparisons for a large number of events of different types.

Indicators for Disturbance Evaluation: A Plant Ecology Perspective

The Hutchinson's model of ecological niche: Hutchinson (1957) has proposed a model of ecological niche in which ecological factors (resources, habitat characteristics) represent the axes of an n-dimensional space and niche represents the portion of that space in which a species growth rate is greater than zero. In the absence of competitors, such a hyper-volume will be greater, and the niche will be a potential niche. In the presence of competitors in large portions of the potential niche, growth rate will decrease below zero, the niche width will be smaller ('realized' or 'effective' niche).

The Hutchinson model is a cornerstone of ecological theory, although it has received many criticisms. In particular, many ecologists think that species can thrive virtually everywhere and so there is no such thing as an ecological niche. According to this view, species presence depends on the fact that propagule dispersal is not hindered by barriers or they are not too far from a source population.

All things considered, this criticism is rather superficial. As far as plant species are concerned (the following example has a general validity), in order for a population to be present in a certain point, the following conditions must be satisfied: (1) the seeds have arrived at that spot; (2) they have germinated; (3) the plant has blossomed; (4) it in turn can produce seeds. Dispersal accounts only for (1), whereas 2–4 depend on niche (potential and realized). In other words, a species presence always and necessarily depends on the interaction between dispersal and niche. The probability of finding a species in a certain spot is given (on first approximation) by the mathematical product obtained by multiplying the probability of species dispersal in that spot and the probability that it grows there. Such a product can be very small and thus suggestive of an irregularity that indeed does not exist. For example, if probability values are both 0.8 (near to certainty) their product is 0.6 (near to the probability that heads comes up after tossing a coin). If values are 0.8 and 0.1 (i.e., virtually there are no barriers hampering dispersal whereas environment is less favorable) probability will be 0.08, barely reaching statistical significance. A species niche can really be very large, but an irregular distribution does not imply at all that *chance* is more important *than* necessity.

Ellenberg's model of the fundamental niche: A second criticism of the niche model is that the number of axes of the niche is potentially unlimited or extremely difficult to evaluate. If this seems particularly true for zoology, as far as plant ecology is concerned, the long experience of phytogeography, which studies plant species distribution on various scales, comes to the rescue. In fact, the number of observations, at least in the temperate zone, is so big that the realized niche of nearly all European and American species is almost entirely known. The potential niche can only be derived from experiment and it is less known although much information is available. The data show that species distribution on a spatial scale ranging from one meter to millions of km^2 is determined for the most part by only a small number of factors: particularly climatic factors, availability of water and nutrients, and disturbances (landslides and herbivores). Ellenberg et al. (1992) showed that in Central Europe, distribution (and therefore realized niche) of essentially all plant species can be described by only seven factors: light, temperature, climate continentality, soil humidity, nutrients, acidity and salinity. Each factor has a level indicated by a number ranging from 1 to 10 and, the seven numbers together constitute Ellenberg's numbers or indicator values (EIVs).

The Ellenberg model as described thus far appears as a niche model. However, the initial definition provided by Ellenberg is slightly different and draws on the gradient concept, which is of fundamental importance in phytogeography. A gradient is a turnover of species composition along an ecological factor. The most classical gradient is on the mountains from base to peak, where holm oak, durmast, beech, spruce and finally alpine plants can be observed. Clearly, such a gradient is related to temperature, but it is defined only by the relative positions occupied by the different species: durmast can be found between holm oak and beech and this is sufficient information to build the gradient, without direct measurement of environmental factors (which is however a very useful methodology, largely utilized by Ellenberg). Reviewing the literature on the subject, Ellenberg summarized the information about gradients, pointing out that there is a limited number of them, which amounts to seven main types. The relative position of each species can be identified by an ordinal number (durmast = 2; spruce = 4) and the ecology of each species can be univocally defined by a set of only seven numbers. Along a pH gradient, the gradient of the above mentioned species is: durmast, spruce, beech, holm oak; durmast is then identified by position 2 along the altitudinal gradient and by position 1 along the acidity gradient. Such gradients relate to optimum temperature value of 17 °C and to optimum pH value of 4.5–5. However, knowing the analytical values of the factors which determine the gradient is not necessary (although useful), since that sufficient information is provided by the knowledge of the gradient itself. If (a) gradients relate to environmental factors and (b) gradients vary in a monotonous way (not necessarily linear) with the environmental factor, the Ellenberg model coincides with Hutchinson's niche geometric model. A number of experimental studies have demonstrated that (a) and (b) conditions are invariably satisfied.

The seven Ellenberg factors are physical factors. One more factor can be added, disturbance, one of the most important gradients which generates ecological successions, in which species turnover is through time and not along a spatial dimension. The disturbance gradient is indicated with the term hemeroby, initially pertaining to urban ecology (Kowarik 1990; Fanelli and Testi 2008) in which it represents an extremely important concept. A list of hemeroby degrees is given in the following Table 4.1.

The equivalence between species and community in the Ellenberg's model: A major breakthrough made by Ellenberg with respect to the Hutchinson model, is the acknowledgment, even though implicit, of the equivalence between species and communities. In fact, Ellenberg has suggested that in order to obtain the community numbers, starting from the numbers assigned to species, the mean (sometimes weighed by abundance) of the species values can be calculated. If a species' niche barycentre is approximately at the center of the niche, such a mean matches the area where species niche overlapping is at a maximum. For example, let us consider three communities, the first made up only by durmasts, the second by 50 % durmasts and 50 % beeches, and the third only by beeches. For the first community, the temperature-related Ellenberg's number will be 2, for the second it will be (2 + 3)/2 = 2.5, for the third it will be 3. Such figures are reliable because the second community is intermediate between durmast and beech communities.

Relying on means and weighed means raises a series of problems which would take too long to be treated in detail here. Such values are very useful when species response is symmetric, the gradient is long and species are more or less evenly distributed along it. If distribution is highly aggregated or markedly skewed (which is often the case), the means show biased results. However, no alternative methodologies have been proposed so far.

Table 4.1 The hemerobiotic scale and typical examples of vegetation types widespread in Europe belonging to each category on the scale (after Kowarik 1990)

Hemerobiotic degree	Vegetation types
I. Ahemerobic	
H0	High mountains; primary forests
H1	Forests with minor wood extraction, open woodlands, old hedgerows, maquis, garigue (*Cisto-Lavanduletea*, *Erico-Rosmarinetea*), vegetation of rocks (*Asplenietea rupestris*), flat or raised bogs, sand dunes
H2	
II. Mesohemerobic	
H3	More intensively managed forests, trampled or heavily grazed forests, developed undisturbed secondary forests, monocultured forests, disturbed secondary forests, riverine forests subjected to flooding, broom and bracken fields, dry grasslands, savanoid grasslands (*Lygeo-Stipetea*, *Festuco-Brometea*, *Trachynion distachyae*, *Tuberarietalia*); a few meadows, alpine grasslands, rocky shores (*Crithmo-Limonietea*), foredunes, embrionic or slightly disturbed sand dunes, screes, badlands (excluding the basal part), disturbed sand dunes, mesotrophic hydrophytic vegetation of waters, saline grasslands (*Festuco-Puccinellietea* etc.), fringe vegetation (*Trifolio-Geranietea*)
H4	
III. Alfa-euhemerobic	
H5	Young planted forests, pioneer stages of riverine forests, young hedgerows, wall vegetation (*Parietarietea*), ruderal vegetation of tall herbs (*Galio-Urticetea*, *Artemisietea)*, neophyte thickets (*Chelidonio-Robinietalia*), managed meadows and pastures (*Arrhenatheretalia*), more or less ruderal rough meadows, fallows (*Brometalia rubenti-tectorum, Agropyretalia repentis*), traditionally managed wheat, barley, rye fields, basal part of badlands where debris accumulate, eutrophic wetlands and reed beds (*Phragmitetea*), annual salt marshes
H6	
IV. Beta-euhemerobic	
H7	Intensively fertilized meadows, trampled lawns, irrigated crops, poorly managed flower beds (*Hordeion leporini*), a few wastelands and rubble heaps (*Chenopodion muralis*), fields and crops affected by strong herbicide impact, flower beds, trampled vegetation of paved areapioneer ruderal grasslands, pioneer vegetation on river debris (*Bidentetea*), perennial salt marshes
H8	
V. Polyhemerobic	
H9	Pioneer vegetation along railways, dumps, salted motorways, eutrophic hydrophyte vegetation of waters
H10	No vegetation or vascular plants

The importance of abstract models: Pure and applied science consists in the identification of cause-effect relationships among variables. However, variable choice affects the relation forms and sometimes hamper their definitions. Let us consider energy concept, which seems obvious, but actually is a very abstract variable, inconceivable before Newton and almost always impossible to be directly measured (for example, mass and speed of an object can be measured and, according to the formula ½ mv^2, kinetic energy can be *calculated*, but not measured). Since they are trained in biological science, ecologists are basically Aristotelian and very suspicious with regard to abstract variables. Many of them, for example, prefer to explain community structure in terms of colonization and casual dispersal, and not in terms of competition. There are no compelling reasons to prefer one explanation to the other, and especially because the two factors act together in essentially every real case. The only difference is due to the fact that dispersal is easy to be assessed while measuring competition may be more difficult. The result is a very impoverished science of community ecology. In such a discipline, usually the variables are number of species, biomass, and range. The fact that a carrion crow is different from a nightingale is dismissed as "idiosyncratic". In other words, biodiversity models are created in which species are not taken into consideration. Species-based models—such as the niche concept by Hutchinson and the analogous by Ellenberg—are inevitably abstract.

When we buy a light bulb, Watt dimensions—kg m^2/s^3—generally do not scare us. Similarly, if we do not let ourselves be intimidated by the multidimensional character of the Ellenberg values, community modeling will be effectively carried out simply by considering species lists, without even the necessity of measuring other variables such as biomass and density. In this way, our models will be far more valuable than those obtained using variables that can be 'seen'.

Hemeroby—indicator of sensitivity to disturbance: Intuitively, habitats can be classified according to the degree of disturbance they experience. A road is more disturbed than a field crop which in turn is much more disturbed than a woodland. We can therefore attribute a score to each habitat type according to the level of disturbance, and this score is the Hemeroby level (from the greek hemeros = cultivated, Jalas 1955; Syeinhardt et al. 1999; Klotz and Kühn 2002). However, analogously to the gradients of the Ellenberg's model, there is a correspondence between sites and species, since species can be classified according to their sensitivity to disturbance. A few species occur only in pristine habitats (e.g., the rare parasitic orchid *Corallorhiza trifida*, many fen species or the white-backed woodpecker *Dendrocopos leucotos*), others in intermediate levels of disturbance (for instance scrub species such as *Pistacia lentiscus* or *Prunus spinosa*, and the birds preferring scrublands), and others occur only in heavily altered environments, such as towns (for instance the allergenic plant *Chenopodium ambrosioides* and *Ambrosia artemisifolia*). Accordingly, we can calculate a score not only for habitats, but also for species.

Hemeroby is not commonplace among ecologists, but there is already a large literature on the subject. It has been applied to forestry (Grabherr et al. 1998), towns (Sukopp 1990; Fanelli et al. 2005), rivers (Testi et al. 2009, 2012) and recently has been extended to birds (Fanelli and Battisti 2014). Extensive databases of hemeroby scores exist for Central Europe (Lindacher 1995; Ziarnek 2007) and other is in preparation for Italy (Fanelli unpublished).

The scale of hemeroby can be arranged on a five point or a ten point scale. The five point scale closely matches the scale of saproby (= eutrofication) widely used in the assessment of water pollution (Kolkwits and Marsson 1908) and can be indicated with the same terminology by substituting saprobic with hemerobic. Table 4.1 shows a list of plant communities with the corresponding level of hemeroby on a five and ten point scale. The scale follows Kowarik (1990, 1999) modified according to the finding that hemeroby is closely correlated with the growth rate of plant species (Fanelli and De Lillis 2004).

Torre Flavia marshland—a case study: Since 1870 and the period of fascism in Italy, the vast wetland located along the Latium coasts, underwent several reclaiming works in different times. The Torre Flavia marsh, situated on the northern coast of Rome (Battisti 2006) and comprising an area of 40 ha, constitutes one of the most interesting of the few remnant areas once pertaining to this large wetland environment. In the last few years, it has been protected as a Natural Monument. In spite of its small surface, the area is characterized by a complex geomorphology: behind the low dunal cordon, a narrow triangular depression which runs along the coast, is narrow in the northern part and wider in the south. Originally the depression was a brackish pond, perhaps originating from a lagoon. Now its central part is flooded with freshwater conveyed by a canal which was excavated to facilitate fish farming. This complex situation causes a mosaic of different environmental conditions, caused by variations in the duration of the inundation period and salinity. Such conditions, in turn, give rise to the existence of an extremely diversified vegetation (Guidi 2006), characterized by numerous hygrophile and halophile communities, distributed according to an essentially concentric pattern.

In order to study an application of the Ellenberg's model, this extremely fine-grained vegetation mosaic is particularly suited. We will only focus on the hemeroby indicator, without developing the model throughout.

Let us start from a halophile association which is located in the northwestern sector of Torre Flavia. The following table shows its species (first column), with the percentage of soil surface they occupy (second column) and the correspondent hemeroby values (third column) (Table 4.2). A complete list of the species belonging to a plot with the associated cover values constitutes a plant species inventory.

This table allows us to calculate the mean value of the hemeroby of plant association through the usual formula of the weighed mean: $\sum h_i C_i / (\sum C_i)$. In this formula, C_i is the cover (the biomass value or another indicator of importance could also be used) of the *i*th species and h_i is the hemeroby values of the *i*th species. In the formula of the weighed mean, the numerator is represented by the

Table 4.2 Case study

Species	Cover (%)	H	$h_i C_i$
Salicornia perennis	70	6.2	434
Aeluropus littoralis	29.5	5.9	177
Salsola soda	0.5	5.2	2.6
Total	100		613

Species, cover percentage (Cover), hemeroby value (H). See text for explanations total value of the fourth column. If such value is divided by the sum obtained from the cover values of the three species, the result will be 6.1 which coincides with the mean hemeroby value of our association.

Using a similar table for each association, the related hemeroby can be calculated. Starting from the vegetation map (Fig. 4.1), polygons of the different associations can

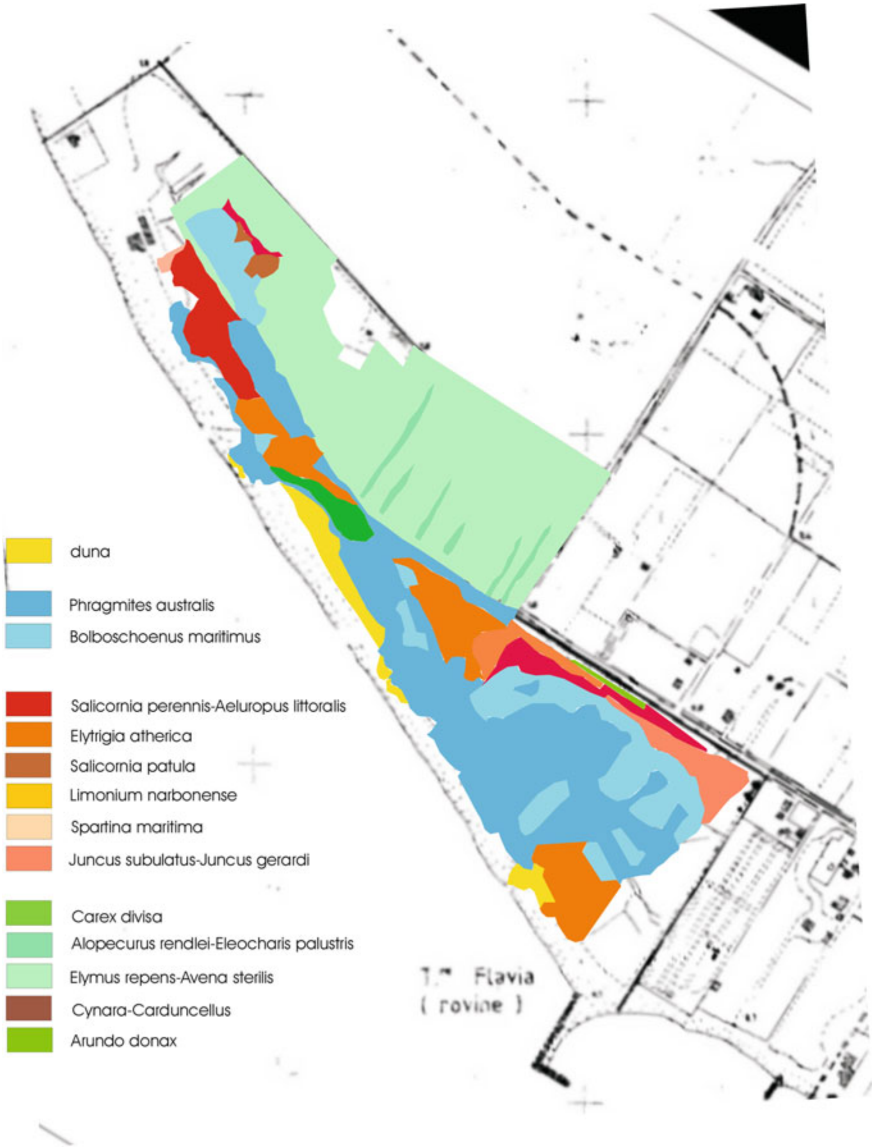

Fig. 4.1 Vegetation map of the Torre Flavia marshland Natural Monument (central Italy, adapted from Guidi 2006)

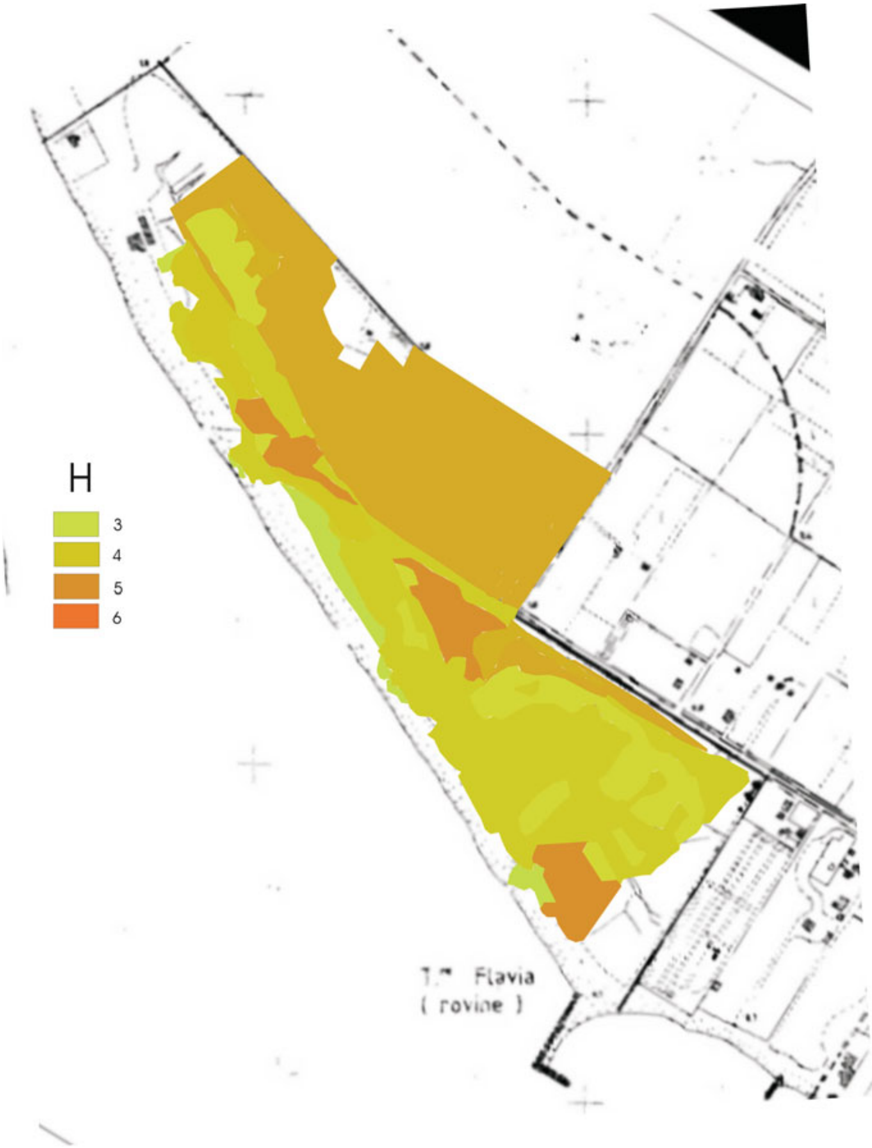

Fig. 4.2 Hemeroby (H) map near the Torre Flavia marshland Natural Monument (central Italy)

be colored with stronger or lighter shades according to the hemeroby level, thus transforming the vegetation map into a hemeroby map (Fig. 4.2).

By studying the hemeroby map, different results can be obtained

1. without taking into consideration the dunal cordon, hemeroby values range from 5 to 8 which are consistent with the impacted character of the whole area;

2. hemeroby in peripheral areas is higher than the one calculated in the central depression, since the impact is greater in the zone adjacent to the surrounding areas, which are highly anthropized.

What do these data imply for the protected area management? Surroundings exert a strong impact on it when considering the very low value of the surface/perimeter ratio. Such value could be increased by realizing buffer areas; the central area, relatively less disturbed, could also be enlarged.

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Chapter 5
Disturbances and Coexistence of Species

Some conceptual models have been proposed to attempt an explanation of the mechanisms of coexistence of species inside environmental systems subjected to disturbances. Some of these models emphasize the role that disturbances (and, more specifically, their regime) may have in maintaining or altering the diversity of species observed in an area (Petraitis et al. 1989; McCabe and Gotelli 2000).

The Intermediate Disturbance Hypothesis (IDH)

According to this model, the effect that a particular disturbance event induces on the number of species in a community (and therefore on diversity) strictly depends on the frequency and/or intensity of the disturbance itself. Infrequent or low-intensity disturbances lead the community to evolve dynamically and to increase its structural complexity through a series of intrinsic processes, such as competition among species and a close adaptation to local conditions. In these communities, a dominance of the most competitive, specialized, and adapted species will be retained, at the expense of less-competitive species. At the opposite, in a community subjected to a high frequency and/or intensity of disturbance, those species with a higher ability to adapt to new conditions will be favored. In fact, in the process of recolonization, less competitive but more opportunistic species, adapted to variable and ephemeral environments, will benefit from the absence of competitors and will take advantage of the new space and resources. The new settlers will establish in the disturbed environments, thus becoming, at least in a first phase, the new dominants[1] in the community (Fig. 5.1).

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[1]Many of these opportunistic species will be r-selected, differently from K-selected ones which are generally linked to more stable and less disturbed environments. In areas of intermediate disturbance, the IDH model thus predicts a coexistence of species with different strategies.

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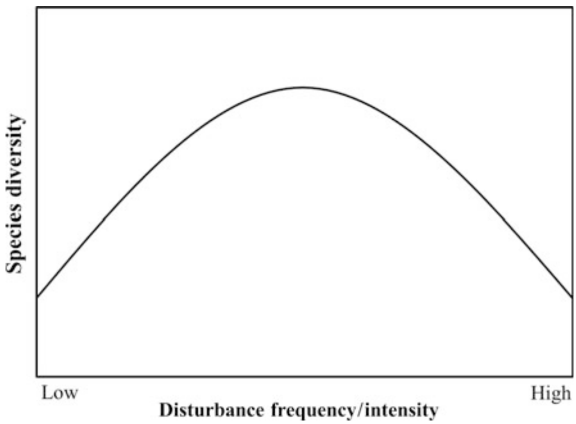

Fig. 5.1 The intermediate disturbance hypothesis which indicates that species diversity within a given patch should be highest at intermediate frequencies or intensities of disturbance (after Connell 1978) (from Hobbs and Huenneke 1992)

The species that were previously more competitive in a stable and low-disturbed environments lost their importance within the community. Due to their high specialization (stenoecìous species) and poor dispersive ability, they show lower predisposition to recolonize an area in the postdisturbance stage. In more extreme cases, where the frequency and/or intensity of disturbance are very high, a recolonization between successive disturbance events would not be possible, and the species forming the community will be reduced to those highly adapted to environments subjected to stress (McCabe and Gotelli 2000).

So, according to the IDH model, the presence of disturbances characterized by intermediate frequency and/or intensity can promote the coexistence and an increase of multiple species in the community (and therefore an increase of specific richness and diversity indexes). On the contrary, in response to events of low or high intensity and/or frequency, a more or less drastic decrease of biological diversity in the area affected by the disruption can occur. In the first case, specialists dominant in stable conditions will prevail, in the second the opportunists tied to unstable and ephemeral conditions will thrive.

There are many evidences pointing out that *intermediate* levels of disturbance (i.e., characterized by intermediate values of at least one of the attributes of the system, in particular, frequency and intensity) can lead to an increase in the number of species in the community (Connell 1978; Hobbs and Huenneke 1992).[2] According to the IDH model, conditions created as a result of an intermediate

[2]However, it is necessary to define the term *intermediate*. It can be considered with both an absolute and a relative meaning. For example, for a species with a relatively long life cycle a once a year recurrence of a disturbance may constitute an event of intermediate frequency (compared to a more frequent disturbance that occurs, for example, once a month or with a less frequent disturbance, such as once every ten years). Conversely, in a species that accomplishes its life cycle in a relatively short period (e.g., within a single year) the terms high, low, intermediate, will refer to completely different periods. In essence, the frequency of discrete events is closely related to and established on the longevity and life cycles of the species that suffer the disturbance.

disturbance event, will allow the coexistence of both strong competitors and specialists (k-selected species), and of opportunist colonizers (r-selected species). This will structure the community to comprise organisms differently characterized in terms of competitive ability, dispersive capacity, and disturbance tolerance (Crandall et al. 2003).

However, in the analysis of the effects of a disturbance, it is important to distinguish between intermediate mechanisms related to disturbance events that act internally to the environmental units (in which all organisms are simultaneously involved in the event: *within-patch mechanisms*), and mechanisms which do not act simultaneously in space and time, that is, with different regime in different patches of the landscape mosaic (defined as *patchy mechanisms* or also *between-patch mechanisms*; see Wilson 1994). In the latter case the species, although subjected to disturbances, may coexist in space or in time thanks to the presence of an environmental mosaic formed by *patches* at different degrees of disturbance and successional stage[3] (*successional mosaic hypothesis*). Within the mosaic, organisms will tend to move away from disturbed *patches*, dispersing and colonizing other *patches*, following the classic immigration-extinction (MacArthur and Wilson 1963) and the meta-population dynamics (Hanski 1994). According to Collins and Glenn (1997) the IDH model can be applied to both mechanisms (*within*- and *between-patch*; Wilson 1994).[4]

The IDH has been verified in various taxonomic groups and with different types of disturbance in marine, freshwater and terrestrial ecosystems. Particularly, high-productivity ecosystems have been studied (tropical forests, coral reefs; McCabe and Gotelli 2000). To date, however, this model has been applied mainly on sessile organisms. As they are unable to escape the environmental perturbations, they can be easily monitored in terms of number of individuals (density) and species (richness), as well as inside the temporal succession of plant communities, where diversity reaches the maximum values shortly after the beginning of the succession itself, to decrease afterwards[5] (Collins and Glenn 1997).

The IDH model is not, however, universally applicable. The evidence relating to a number of exceptions observed for at least some taxonomic groups and in certain

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[3]We mentioned the role of disturbance in promoting diversity at landscape scale, allowing the structuring of environmental mosaics (or eco-mosaics) formed by different *patches* due to the different intensities and frequencies of such events. This heterogeneity may play an important role in promoting the coexistence of species, especially in those landscapes where disturbances occur with intermediate frequencies and intensities (Roxburgh et al. 2004). In such contexts, the undisturbed *patches* may be used as a refuge by the susceptible species and act in the medium to long term as source areas of re-colonization (*source patches*).

[4]The distinction between the *within*- and *between-patch* mechanisms is also linked to the scale of analysis. If the total area in which a disturbance is acting (*disturbance area*) is wider than the sampling area, within-patch mechanisms are under study; if the disturbance area is less extensive than the sampling area, between-patch mechanisms are considered.

[5]In this case, the term *intermediate* is referred to the distance in time from the beginning of the post-disturbance succession.

conditions, have led in recent decades to a critical debate on the general and indiscriminate application of the model to environmental systems with characteristics different from those it has been tested until now (Crandall et al. 2003). One of the first criticisms showed that the IDH model proves to be too simplistic when compared with the complexity of the processes that give rise to the structure of the community (McCabe and Gotelli 2000; Roxburgh et al. 2004). Furthermore, the fact that, as mentioned earlier, the IDH has been clearly observed in only sessile organisms, does not allow to automatically conceive it as a model applicable to vagile organisms. Sessile organisms are in fact rooted to the substrate and, therefore, cannot circumvent the disturbance events. In this case, the colonization of non-disturbed areas is only possible via propagules dispersed by organisms.

The effects on vagile organisms may well be rather different. Being adapted to avoid possible disturbances, these organisms can get away from the sites where the event occurs and, in the case of frequent and/or high intensity disturbances, they can move away from the disturbed site, to return if conditions permit. This implies that in vagile species the expected decrease in species richness as a result of intense and/or high-frequency disturbance events cannot occur. Following extreme events, the large amount of sessile organisms that perish can also be a resource for mobile organisms and, contrary to the model prevision, an increase in the total number of individuals and species can be observed (Crandall et al. 2003). In conditions of maximum frequency and/or intensity of a perturbative event, the increase in density and richness in organisms at high vagility (such as many large vertebrates) may also initiate mechanisms of competition that are theoretically expected only in communities subjected to low-mid levels of intensity and frequency of disturbance (i.e., in stable or slightly disturbed systems). In that case, the big picture becomes more complex and unpredictable.

A further criticism has also shown how the IDH, assuming a high degree of interactions among species (e.g., competition), ignore the limiting role at the local scale of other physico-chemical factors that, together with the disturbance themselves, have their impact (Crandall et al. 2003).

Beyond the non-universality of the phenomenon and the criticisms that have emerged in recent times, the IDH is however a conceptual framework of reference that can explain the diversity present in biological communities according to the dynamics of extinction-immigration between patches. This model is configured as a complex pattern resulting from different mechanisms that help explain the coexistence of species in the medium to long term (Roxburgh et al. 2004).

The Huston Model of the Dynamic Equilibrium

According to this model, contrary to what the IDH model predicted, the species richness can reach a peak at a low, high or intermediate level of disturbance. Besides the entity of the disturbance, the species richness of the community may be affected also by additional internal features, such as competition and demography of populations of individual species. More specifically, coexistence and richness in the community may depend not only on the event of disturbance in itself, but also: (i) the rate of competitive exclusion internal to the community and (ii) the rate of growth of population.

This model offers a wider range of predictions than the classical IDH. It is based on the assumption that competitive exclusion can be directly correlated to the rate of population growth. As a consequence, the following predictions can be made.

- For low rates of both population growth and competitive exclusion, the highest species richness is achieved at minimum levels of frequency and intensity of disturbance;
- For intermediate growth rates and competitive exclusion, species richness in a community reaches a peak at intermediate levels of disturbance (as required by traditional IDH);
- For high rates of growth and competitive exclusion, species richness peaks at maximum frequencies of disturbance.

In essence, the difference between the IDH and the model of the Huston dynamic equilibrium is in the position of the maximum peak of diversity which, in the first case (IDH model), is achieved in conditions of intermediate frequency and intensity, while in the second (Huston equilibrium), depends on the rate of population growth (and, secondarily, on competition; Huston 1994; McCabe and Gotelli 2000).

The Model of Gradual Climate Change (GCC)

According to this model (Wilson 1994; Collins and Glenn 1997), the gradual change in environmental conditions (e.g., those due to the seasonality in temperate areas) prevents most of the species to achieve dominance in a stable community, thus enabling the coexistence of multiple species in different periods of the year.

The GCC and IDH models differ in many ways. In the first model, the environmental changes are gradual, in the second they are represented by discrete events and the effects are, in general, more pronounced. The two models can operate simultaneously in the community to explain the composition, structure and coexistence of species with different ecology. For example, at seasonal level, the GCC model can explain how gradual changes of environmental parameters may influence the phenology of species, allowing the coexistence over time of a higher number of taxa that will periodically change (turnover) on a relatively large territorial scale (e.g., regional areas). On a different scale (e.g., on individual sites), the IDH can instead explain the coexistence of species in the community as a result of disturbance events, the latter limited in time and space.

Although working at different scales, both mechanisms simultaneously affect biological communities. The impact of a local disturbance will depend, therefore, on how it will be placed along the time scale of manifestation of the GCC. For example, the same perturbation may cause different effects if it occurs in different seasonal periods. Because of the overlap of gradual (e.g., seasonal, GCC) and discrete (local disturbances, IDH) processes, tracing the mechanisms explaining the coexistence of species in a site can result in an arduous effort.

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Chapter 6
Classification Criteria for Disturbance Events

An event is a simple process
with a well-recognized beginning and end
(Gotelli and Ellison 2004)

Disturbance events can be classified according to different criteria. Among them are the origin, the type of agent which triggers the event, the regime and impact modalities, the relative collocation and type of relationship with the environmental components, and the vagility of the latter.

Criteria Based on the Origin and Agent Type

A first classification can be made with respect to the origin and type of the event-triggering agent. According to this, disturbances can be distinguished into *natural* disturbances, when they are not, even indirectly, induced by human activities and *anthropogenic* (or *human-induced* disturbances) when they are either directly or indirectly caused by human action. Human intervention can potentiate or limit some natural effects, sometimes with indirect and complex modalities: in this respect there may be found many intermediate situations of uncertain attribution. For example, a flood caused by extremely severe weather conditions (natural disturbance) can show much higher duration, frequency, extent, and intensity when it occurs in an area subjected to deforestation (anthropogenic disturbance). Other examples can be drawn considering the meteorological events which, in an age of global warming, can be indirectly induced by human action. Therefore, if disturbances are classified according to such distinctions, an evaluation of the degree of human manipulation along a continuum scale or by categories can also be considered (e.g., by distinguishing the degree of natural event manipulation being it low, intermediate or high, Dornelas et al. 2011).

Maintaining focus on the causal nature of the perturbation event, disturbances (both natural and anthropogenic) can also be distinguished as biotic, if mainly

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Environmental Science and Engineering, DOI 10.1007/978-3-319-32476-0_6

caused by organisms, and abiotic if originated by physical, chemical, or climatic events (e.g., in the case of terrestrial, atmospheric, geological, geomorphological, and hydrological disturbances; White and Pickett 1985; Mackay and Currie 2001). Other authors (such as Davis and Moritz 2001; Dornelas et al. 2011) have preferred to make a distinction among mechanical, physicochemical, and biologic disturbances. Each class of mechanisms shows typical and distinctive characteristics with respect to their functioning and to the impacts exerted on different types of organisms.

Specifically, mechanical disturbances are often nonselective and their impact may depend on the organism's capacity to resist and by their collocation, size, and density. Generally in a site, mechanical disturbances cause biomass and resource withdrawal, increasing the patchiness of the affected area (Levin 1992).

In contrast to disturbances induced by mechanical agents, physicochemical disturbances may cause in situ biomass depletion through the action of physiological stress acting on single individuals or propagules (e.g., impact on cells, tissues, and organs). Such stress can interfere with organismic metabolism and growth, leading to variations in weight and physiological state. The impacts exerted by physicochemical disturbances are specific, and vary among different organisms. They depend on the tolerance (or sensitivity) of the species to which the organisms belong and, within the same species, on individual age, sex, and fitness (physiological state). In such a way, these type of events can operate a strong intra- and interspecific selection within communities.

On the contrary, the category of biological disturbances includes all those events operating through the action of consumer organisms (e.g., herbivores and predators), parasites and pathogens which remove biomass amounts, often in a selective way, at the scale of the individuals (they include the competitive interactions, those between predator and prey, host and parasite, and herbivore and pertaining plant species). Contrary to what happens with mechanical and physicochemical disturbances, in the case of biological disturbances biomass can be concentrated, converted, and redeposited often in different sites from the occurrence of the event.

Disturbance categories are not always so clearly recognizable. For example, some biological agents can also act as physicochemical and mechanical ones. They can actively modify the environmental mosaic and affect the distribution of vegetation and nutrients, alter water movements, and, more generally, the dynamism of the disturbed patches (e.g., through trampling, digging, and fecal deposition).

All those perturbations which are either directly or indirectly produced by human intervention constitute a peculiar class of biological disturbances. Human species have manipulated and altered natural ecosystems for many thousands of years causing different impacts on ecosystem structures and functions as well as on density and distribution of the individual populations, species, and communities. As mentioned, all human activities can in some way interfere with natural disturbances (as in the case of fires, floods, and other weather events and of the activities of many animal species) by deliberately or unintentionally altering, interrupting, or catalyzing them. The disappearance, conversion, fragmentation, isolation, and deterioration of natural ecosystems, the physicochemical and biological alteration of inland and marine waters and soil, the exploitation of biotic and abiotic resources constitute the extensive human-induced disturbance categories (*threats*) which intrude into natural processes and lead to a spatial-temporal alteration of their original regimes. The interrelationship between natural and anthropogenic processes may generate different feedbacks with various degree of predictability, thus hampering the recognition of their origin and complicating the analysis and definition of mitigation, control, and management strategies.

Criteria Based on Regime and on Impact Modalities

Disturbances can also be classified according to their regime characteristics. For example, the frequency of occurrence of given events and their extension can also become, respectively, temporal and spatial criteria for classifying disturbances. As far as frequency is concerned, disturbances can be classified into *chronic* (when they repeatedly occur over long periods of time with varying intensity and affecting sensitive targets; also compare *press* disturbances as in Gotelli and Ellison 2004), *acute* (when they occur for brief periods at high intensity, as in the case of *pulse* disturbances, Gotelli and Ellison 2004), *periodic* (when they occur periodically with varying frequency), or *episodic*/*occasional* (when they rarely occur and, either show a low degree of predictability, or are completely unpredictable; Martorell and Peters 2009). In all cases, the frequency and intensity of occurrence, and so the category to which the disturbances belong, according to the above-mentioned criterion, can be calculated both in an absolute way and in relation to the sensitivity of the environmental components which are affected by the event.

With respect to impact modalities, a distinction can be made between *species-specific* (or *target-specific*) disturbances: i.e. disturbances which specifically act on a single environmental component (a single population, plant community or ecosystem type) and *random* or *non-selective* disturbances (not species-specific) whose action on various environmental components within a definite spatial context is randomly and non-specifically put into effect (Mackay and Currie 2001).

In analogy with this classification, perturbations can be subdivided into *selective* and *catastrophic* events. Selective events, for example, cause selective individual and species mortality within target communities, increasing diversity or maintaining it at a high level. Catastrophic events produce catastrophic non-selective mortality leading to an overall severe imbalance in the systems (Mackay and Currie 2001). Certain kinds of catastrophic disturbances not only can alter animal and/or plant biomass in a site, but also affect the physical substrate and the abiotic components of the ecosystems (Blumstein et al. 2005; Mackay and Currie 2001). With respect to these kind of events, some authors (see Sousa 1984 for further references) have made a distinction between *disaster* and *catastrophe*, the first being considered as a perturbation of medium-high intensity which recur fairly often in a site, while the second is an event characterized by extension, frequency, and modality of exceptional level with respect to the spatial and temporal scale of sites and targets. Disasters can occur once or twice within the life cycle of one or more sensitive species and yield short/long-term consequences (also selecting resistant genotypes in the following generations and thus playing an evolutionary role). On the contrary, catastrophes show a very infrequent recurrence and so biological organisms may not evolve adaptive mechanisms. In this case, the evolutionary consequences, which are relevant for the physiological state (fitness) of the individual organisms in successive generations, can be limited. However, at least in certain conditions, such events may have medium- and long-term genetic and evolutionary consequences. For example, populations which have experienced a marked reduction in number following a catastrophic event may undergo a demographic bottle-neck effect with consequences on their genetic characterizations in the subsequent generations.

Among the disturbance characteristics, the extent, in relation to the target or to the reference site, allows us to subdivide disturbance events into at least two main categories: large-scale disturbances and small-scale disturbances. While the former can act on wide-ranging areas (e.g., on landscape and regional scales), the latter act only on the scale of the single environmental units (populations, plant associations, and/or patches). Clearly, there exists a series of intermediate conditions which do not belong to such extreme categories.

Criteria Based on the Relation Between Disturbance and Environmental Components

A distinction made on the relative collocation of disturbances with respect to the affected environmental component or system also allows further grouping of the perturbation events into either *endogenous*, when they are internal to the system, or *exogenous* if they are external (Davis and Moritz 2001; Mackay and Currie 2001; Blumstein et al. 2005; for the species level see Fig. 6.1). In endogenous disturbances, the probability of occurrence depends on the status of the system and on factors which are intrinsic to it. On the contrary, in exogenous disturbances, the probability depends only on factors and processes associated with the external environmental context.

Disturbances can also be defined on the basis of the indirect or direct relation with the environmental component on which they exert their pressure. *Direct* events are able to affect directly an attribute of a particular system or environmental component (e.g., the individual survival rate or the sex ratio of a certain target population; the predator species richness or a community's macro-benthic biomass; the salt concentration in a given water volume of a marsh ecosystem).

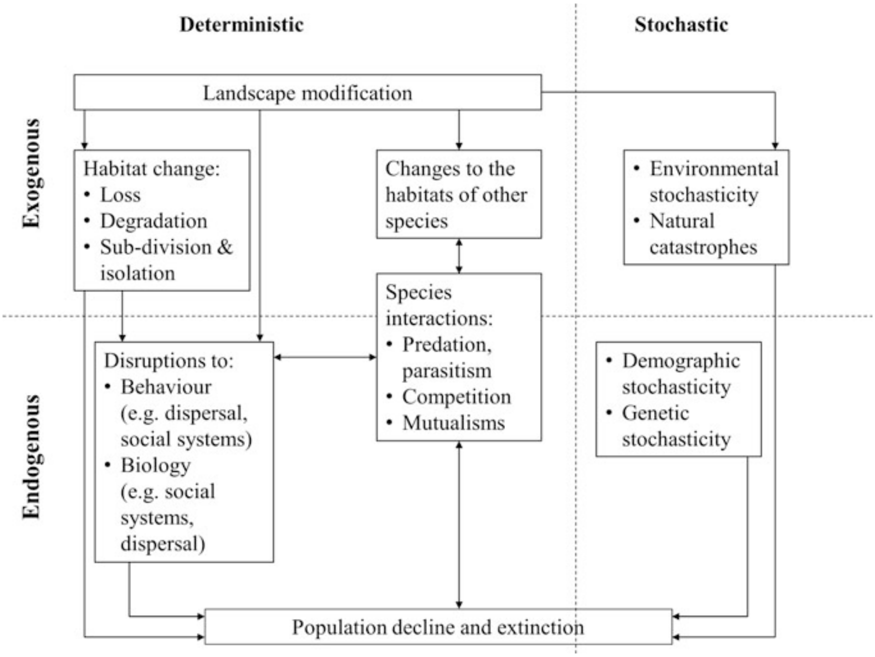

Fig. 6.1 This diagram has been extracted from a research paper about human-induced effects of landscape modification (fragmentation) on biological species (Lindenmayer and Fischer 2006). It highlights a distinction between deterministic versus stochastic events with respect to their being either exogenous (external to the reference system) or endogenous (internal)

Indirect events affect ecological system in an indirect way: in such cases disturbances may alter resource availability (or modify certain parameters and environmental conditions) and subsequently influence organisms and propagules (Brawn et al. 2001). For example, a river flooding can carry a huge amount of sediments. Such materials inundating the river bottom and the surrounding/adjacent areas may subtract resources to higher trophic level consumers (e.g., fish and birds), thus inducing a local demographic decline of their populations. Therefore, the flooding event represents an indirect disturbance which, reducing resource availability (and thus environmental suitability) for local bird and fish species, decreases their diversity.

Criteria Based on Target Vagility

In certain conditions and for certain types of events it can be useful to identify disturbances *on the basis of the vagility degree* or the *dispersion ability of the target components* undergoing the events.

Further classification criteria can be devised considering the dynamic state of the target component which has been affected by the impact (e.g., events on primary and secondary successions), the types of alterations induced by disturbances on ecosystem processes and services, the degree of predictability (*stochastic* or *deterministic* disturbances), and their ability to propagate (Davis and Moritz 2001).

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Chapter 7
Categories of Natural Disturbances

Disturbances of natural origin comprise many categories of processes, for example, fires, floods, extreme meteorological and marine events, water stress and other perturbations associated with hydrological dynamics, grazing, and predatory activities by consumer organisms at higher trophic levels. Moreover, they include all those events which can be connected to intra- and interspecific relationships (Sousa 1984).

A first important distinction of disturbance typologies can be made by grouping them into two different categories: abiotic disturbances (caused by physicochemical and mechanical agents) and biotic disturbances (whose origin can be attributed to the action of living organisms).

Abiotic disturbances originate from non-biological natural components and include processes and factors generated by different forms of light energy (e.g., UV light), mechanical energy (for example meteoric waters, sea currents, winds, landslides, deep and surface crustal movements) and chemical energy (gas emissions, salinity gradients and the many alterations which affect soil, water, and atmospheric chemical composition; Brawn et al. 2001).

The biotic disturbances include all the events produced by living organisms. Among them: biomass removal by herbivores (grazing activity), excrement deposition, deposition of biological excreta (e.g., urine and uric acids), trampling, overturning of soils and grass clumps, digging of tunnels into the soil and of cavities in organic substrates.

Natural disturbance regime is tightly connected to the ecology, density, distribution, behavior, and diurnal cycles (as well as seasonal and nocturnal ones) of species and communities. A species' predation rate, for example, can be the consequence of specific factors such as the presence, density, physiology, fitness, and behavior of both predator and prey. Other factors can also be added: the presence of alternative prey, availability of shelters for the latter, as well as factors which are external to the species, such as complexity of the ecosystem itself (e.g., plant stratification which affects visibility). Therefore, a biotic disturbance regime can

C. Battisti et al., *An Introduction to Disturbance Ecology*,
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Table 7.1 Main types of natural disturbances subdivided with the criterion of the abiotic or biotic origin

Abiotic disturbances	Biotic disturbances
UV radiation	Demographic explosions and alien species' invasions
Drought events	
Fires	Epidemic diseases
Rainfall and snowfall, events linked to strong winds, ices and other meteorological events with different regime	Predation
	Sedimentation of organic litter
Flooding events and other processes linked to river and sea dynamics (e.g. coastal erosion)	Constructive activities (e.g., by beavers, termites)
	Excavation and tipping soil (e.g., by small mammals, red-deer, wind boars and other ungulates)
Change in salinity and in other chemical factors in water and air	Trampling by animals
Landslides, earthquakes, volcanism and other geological events	Grazing

depend on several local factors. They can be specifically biological or connected to the territorial context.

All the events, being they mechanical–physical, chemical or biological, can act on different spatial and temporal scales and on other natural components and relationships, affecting sensitive organisms by damaging them (negative impact) or, on the contrary, favoring them and creating opportunities (positive impact).

In the following section, the characteristics of the most relevant natural events, both biotic and abiotic (reviewed in Sousa 1984; Hobbs and Huenneke 1992; Blondel and Aronson 1999; Brawn et al. 2001, Table 7.1) will be synthesized in order to give a brief overview of the issues involved. For an in-depth analysis, we refer to the ample literature available.[1]

Flooding and Other Events Connected to River Dynamics

River floods comprise a series of physical processes which occur periodically (for example, seasonally) and generates moderate to severe perturbation of riverbed structures. These are characterized by specific geomorphological and hydrographical structures and by absolute and relative geographical collocations (e.g., with respect to the position along the hydrographical basin: along the main river, in the estuary, in coastal zones, etc.). The occurrence of such events may lead to selective

[1]Moreover, we refer you to the specific literature on natural disasters for the disturbances which damage human populations.

differentiation and adaptation of plant and animal components usually found in the riverbeds. Moreover, it can cause local extinctions as well as new colonizations, and, consequently, population, species, and community turnovers both in space and time with a medium-term increase of environmental diversity (β-diversity).

Plant organisms colonizing these environments are extremely sensitive to the local hydrological regime and their presence along the riverbed is strictly connected to a range of peculiar conditions. The spilling off of water from the riverbed (flooding) and the recurrence of the flooding events themselves, in consequence of which plants can be completely submerged and/or cut down represent a disturbance for those species which have not evolved the ability to adapt to sudden changes of their conditions. On the contrary, for other species, such events represent an opportunity. Among riparian tree species, willow trees (*Salix* spp.) are a good case in point. They are characterized by high degree of resistance and resilience to flooding events, having evolved over time quite flexible branches which can bend adapting to the direction and intensity of the river flow/current and developing a specific ability to disseminate by cutting. Thanks to the flooding events such species can colonize new areas along the rivers and in the flooded area.

Flooding events are characterized by a trend over time and patterns in space which can be distinguished in several phases (intensity/time plots with time intervals between peaks in rainfall events and peak in flow, rising limb, recession limb, etc.; for an in-depth analysis we refer to the specialized literature; see for example Alexander 2001).

Fires

Fires constitute a typology of disturbance which can markedly affect biotic and abiotic ecosystem components. It can influence species composition and diversity and consequently ecosystem and community structure and functions. Important attributes of its regime are: intensity, frequency, extent, and period of the year. They depend on a range of factors and interrelations which can be intrinsic and extrinsic to the event; among them: frequency and seasonality of the event-triggering causes, humidity level/degree/rate, and other variables connected to the meteorological, climatic, and topographical conditions of the site (wind, exposition, etc.), the structural and physicochemical characteristics of the fire, the characteristics of the environmental mosaic, the vegetation type, the rate of accumulation of flammable materials. In particular, prolonged drought, strong winds, easily inflammable accumulated materials, and human-induced habitat fragmentation with the establishment of many transitional areas (ecotones) between fragments of spontaneous vegetation and open areas constitute factors which strongly predispose to fires. The season during which the phenomenon occurs (for example, spring and autumn) is important to evaluate its impact on certain environmental components.

In analogy to other disturbances (for example grazing), fire has a range of immediate effects: (1) reduction of vegetation heights and rearrangement of its structure, (2) replacement of perennial woody vegetation with annual herbaceous species, (3) overtime modification of plant inflammability levels, favoring opportunistic species with sclerophyllous leaves and decreasing litter decomposition rate; (4) reduction of the overall plant biomass.

In some vegetation typologies, fire (namely, the ecological factor which starts the burning) represents a fundamental element which enables an increase of environmental heterogeneity at landscape scale and maintains high levels of primary productivity in the ecosystems, by creating open zones with low herbaceous vegetation or with vegetation of lower structural complexity. Therefore, a decrease of biological diversity on the scale of the single patch or environmental unit (α-diversity) can be associated with an increase of β- and γ-diversity (i.e., of turnover diversity among sites and of overall diversity at landscape scale, respectively). Moreover, fire can favor the existence of all levels of ecological successions, facilitating the maintenance of an articulate forest mosaic at intermediate or large spatiotemporal scale (landscape and regional scales). In the absence of recurrent fires, certain categories of environmental systems would tend to evolve, over time, into an increasingly homogeneous mosaic characterized by few highly specialized species linked to stable conditions (*climax* stage).

Fire, with its renewal effects on some or all vegetation layers (depending on its intensity) and in creating new open zones, can favor the presence of heliophytes, requiring full sunlight conditions to grow and decrease the species linked to the understory. Moreover, fires alter the nutrient cycle along the vegetal successions favoring those species which show a high level of specialization to the new conditions (for example, the Leguminosae). Such disturbance can therefore start a process of soil fertilization determined by a transient light and nutrient increase, even though it can occur only in the short term (Crandall et al. 2003).

Some plant communities are also dependent on fires or historically have been adapted to it, as in the case of the Mediterranean maquis and of some coniferous forest associations. Some of these environments are so adapted to such perturbation that the artificial suppression of fires can itself become a disturbance, in this case of anthropic origin. In these types of environments, when fire are prevented or artificially controlled, plant community structure can be severely altered. In particular, native fire tolerant species and species which are adapted to recurrent fires (such as those whose germination is dependent on them, *obligate-disturbance species*) can disappear. Fire suppression can generally reduce the frequency of fire occurrence in the short term, but can potentiate the severity of the phenomenon when it rarely occurs, with consequences on ecological and conservation issues (see also Cole 1994). Therefore, maintaining fire periodicity (and natural regime) overtime is of great importance (ESA 2000; Hunter et al. 2001; Lorimer et al. 2001; Spies et al. 2006).

Fire plays a fundamental role in the balance of certain ecosystems: while some species may not be resistant to its direct action, many others have evolved adaptive responses, increasing their resilience and even benefiting from it.

When occurring in environments, such as tropical zones or high-altitude tree–shrub ecosystems (e.g., beech woods) which have not experienced its action in historical times, fire can irreversibly damage the structure and composition of the environmental systems, leading to the subsequent reduction of the overall number of species and of their interrelations (simplification). By contrast, areas subjected to recurrent fires (for example, Mediterranean and subarid environments) have been adapted to fire and at present they show high resilience to this type of disturbance. However, when occurring at high frequency, fire can start a process of progressive and irreversible alteration also in these types of ecosystems (as in the case of desertification).

As mentioned above, Mediterranean regions constitute an example of ecosystems in which fire is essential to maintaining canopy structure and that of the intermediate layers of successions (maquis, garigue, chaparral, fymbos). Also in such cases, defining the optimal regime beyond which such events become a disturbance instead of an opportunity, and regardless, a mechanism capable of producing ecological processes, is a task of the project team which is in charge of devising conservation strategies.

With respect to the effects of fire on animals, three categories of species can be identified which are separated on the basis of their temporal reaction to the event: (1) opportunistic species which colonize the burnt areas soon after the event (e.g., in the Mediterranean region, among birds, the ortolan bunting, *Emberiza hortulana*) (2) species tied to the early stages of shrub vegetation evolution which utilize the new habitats and resources shortly after the event (1–2 years later; for example some species of passerine birds belonging to the family *Silvidae*); (3) species which are more sensitive to fire and colonize the disturbed areas only many years later, when vegetation has attained a new stage of maturity (climax species, tied to stable conditions).[2] Over time substitution of these groups of species accounts for high temporal turnover in fire burnt environments. In any case, fire-induced changes in vegetation structure yield an ample range of effects related to predation and competition mechanisms (for example, higher accessibility of nesting sites and a consequent increase of predation and parasitism rate on birds' nests).

For further in-depth analysis, we refer you to the specific literature on the subject (see, for example, Borghetti and Giannini 1998).

[2]As far as birds are concerned, there are many species on which fire exert positive effects because they are capable of colonizing newly burnt areas. For example, some species belonging to the order Piciformes which utilize necromass as trophic site, as well as ecotonal (edge) species (spotted flycatcher, *Muscicapa striata*, and other passerine birds of the family Sylvidae) and/or those species tied to the newly available resources (granivores, generalist omnivores; for Italy see also Ukmar et al. 2006). Since they can be easily sampled, birds are an extensively studied group of higher vertebrates.

Extreme Meteorological Events

Extreme meteorological events can exert a huge impact on some species' populations as well as on the structure and composition of entire communities (e.g., migratory birds; see Newton 2007).

Among the different types of meteorological precipitations, snow constitutes an important seasonal agent of disturbance which acts on mountain ecosystem vegetation and more episodically on that of hills and plains. In the same way as fire, snow regime depends on a range of factors, conditions, and environmental circumstances capable of amplifying its effects. Its distribution, in fact, depends on topography and on dominant wind direction. Snow accumulates unevenly and for different periods of time depending on soil exposition. It can form massive piles which affect spring vegetative growth and alter the soil water content as well as their temperature during thaw season.

This disturbance regime varies according to season, and depends on the amount of accumulated snow and the velocity at which snow melts (with possible extreme consequences like avalanches). Unlike what happens in flat and hilly lands, in mountain areas, vegetation is strongly adapted to the presence of persistent snow cover, so much so that vegetal associations specifically structured for this type of environment have evolved overtime. Dwarfism and apical meristems deeply rooted into the soil are only some of the ecological and evolutionary strategies adopted by the herbaceous plants to cope with the adverse environmental conditions caused by the presence of persistent snow layers. In analogy to what has been mentioned in the case of fire, for the species adapted to periodic snow coverage, alteration of meteorological and accumulation regime of such events (as it is currently already emphasized by ongoing climatic changes) can constitute a disturbance in itself.

In many temperate and tropical ecosystems, wind is an important disturbance agent, which among other effects, can create openings of various size in forest cover. In forest environments, wind-induced tree falls (gap disturbance) is a fine-grained, temporally asynchronous event. It is capable of altering soil characteristics (chemical, structural, and topographic) and microclimate of the affected site when compared to adjacent forest areas (Wiens 1989). Such an event has a point distribution but its effects can be detected at the scale of the entire forest systems.

Tree fall dynamics show considerable variation depending on the vegetal species involved and on substrate. Gap dimension varies according to modalities and circumstances of tree falls: for example, on loose and incoherent terrains, the fall of a big tree not only produces openings in the crowns of adjacent trees but it also raises the root apparatus and, as a consequence, induces the formation of soil hollows. The latter can in turn provide new habitats and niches (ephemeral wet environments, dens, nesting sites, etc.) to colonizing species (mostly herbaceous plants, invertebrates, small mammals, reptiles, amphibians). The fall of individual trees enables the so-called edge species, external to the forest stand, to occupy the 'gaps' originated by wind, increasing heterogeneity both at local scale (β-diversity, namely the rate of species substitution among sites) and at landscape scale (γ-diversity). By creating greater environmental heterogeneity, many new resources are made available to plant and animal organisms by forest gaps.

Intense rainfalls are also included among extreme meteorological events which trigger a series of hydrological and geomorphological effects (at local and hydrographic basin scale, see the following paragraph). Phenomena induced by extreme alteration of rainfall regime or by their absence (prolonged drought) come also under the same category and trigger a series of events of considerable importance (e.g., desertification).

Water Fluctuations

Periodic or occasional water fluctuations are events related to coastal marine environments, basins, and freshwater streams of any dimension. Such fluctuations depend directly or indirectly on other events and factors (tides, wave-motion, drought, and other meteorological and climatic conditions such as severe rainfalls, natural or human-induced modifications of the water stream, etc.) which, also in relation to the environment nature itself, determine the disturbance regime.

Water fluctuations can lead to the accumulation or loss of sediment material and, therefore, to physical and chemical change of the substrates usually utilized by organisms. As a consequence, this type of disturbance primarily acts on sessile organisms or on organisms which have a reduced capacity to move about and depends on a substrate for their survival (Fig. 7.1).

In analogy to other natural disturbances (for example, fires), floods and other extreme flooding events can increase the environmental heterogeneity through creation of new wet environments, the availability of sedimentary deposits, the removal of preexisting vegetation and consequent start of new successions, and with turnovers of plant communities over time. In flooded areas, every plant community self-organize in definite zones often separated by marked transition areas (ecotone strips) which reflect frequency and intensity of the disturbance (Rosenberg et al. 2000). Moreover, such events, thanks to the amount of newly deposited soils, can trigger the start of primary productivity, promoting rapid species turnover as well as dynamics of local plant and animal communities. In particular, recurrent seasonal floods can promote high diversity and productivity of the systems affected by such events (flood pulse concept; Junk et al. 1989). The highest biological diversity is attained by rivers of intermediate size with intermediate levels of disturbance (river continuum concept; Vannote et al. 1980; see Intermediate Disturbance Hypothesis).

Water course size can explain overall magnitude and predictability of seasonal flood pulses. Alteration of water fluctuation regime due to human activities (as in the case of dam construction, regimation of drainage channels, and lowering of water table for agriculture) is classified as anthropogenic disturbance and can heavily affect overall hydrological system structure and functioning.

Similar to natural floods, sudden water level decrease represents a natural disturbance characterizing wet environments, especially in Mediterranean regions.

Fig. 7.1 A flooded littoral area with rushbed vegetation (Juncetalia maritime) and *Sarcocornia perennis* (*Photo* Corrado Battisti and Giuliano Fanelli)

Many species have adapted to such disturbance (for example, wading birds, which, during migration, take advantage of the muddy shores emerging as water decreases). Also in this case, human activities may interfere with water regime, making it more stressed and consequently exerting a negative impact on numerous species and biological communities.

Geological Events

Such disturbances comprise a wide class of phenomena linked to the lithological and geological characterization of an area, namely landslide events, erosion by physicochemical climatic and biological agents, seismic and volcanic events. They are capable of transforming, also irreversibly, substrates, ecosystems, and communities and can start short-, medium- and long-term processes of recolonization which in turn triggers further physical and biological events. For further reading we refer to the extensive literature on the subject.

Biotic Agents: Pathogens

Viruses, bacteria, and fungi are classified among disturbance agents which mainly affect composition and structure of plant associations and animal communities. Their diffusion and effects can yield dramatic changes in the structures of entire areas, especially modifying mortality and reproductive rates of the populations which are sensitive to the events. Such disturbances, often highly selective, exert profound effects on a great number of organisms. Their diffusion and virulence also depend on the environmental context in which they originate and diffuse as well as on the presence (and regime) of other possible local disturbances.

Biotic Agents: Animal Disturbance

Disturbances raised by animal species are common in all natural environments and are connected to the various functions performed by organisms over their diurnal, seasonal, and life cycles. Such disturbances can be grouped into at least five general categories: trampling, grazing, tunnel digging, feces, and urine deposition (Table 7.2).

Trampling: Trampling caused by repeated wild animal passing (e.g., rodents and ungulates) exerts considerable influence on plant populations, favoring those species which are more resistant to mechanical compacting. In fact, soil compacting decreases water absorption and prevents gas circulation into soil with a progressive reduction of microbial activity and therefore of humus layer. This last effect can induce, in the medium/short-term, plant cover reduction and trigger erosion processes.
Grazing: Grazing can produce very different effects which are dependent on the herbivorous species involved, the plant species consumed (each with its own tolerance), climatic conditions and type of vegetal cover. In general, grazing enables the selection of certain species characterized by mechanical (e.g., spines) and chemical (repulsive substances) defensive mechanisms. In other cases, less edible and palatable plants (i.e., with greater fiber content) are selected. Generally, under

Table 7.2 Main effects of some animal-driven disturbances on ecosystem components

Disturbance	Main effect at short term
Trampling	Soil compacting and alteration
Grazing	Disruption of biomass, species turnover, change in species dominance
Animal excavation (dens, galleries)	Damaging of plant roots, change in soil chemistry
Plowing	Change in parameters related to herbaceous vegetation
Feces and urine	Increase of nitrates, change in soil pH

certain grazing regimes (specifically at intermediate frequency and intensity), such disturbance can alter composition and productivity of herbaceous environments, maintaining high levels of plant species diversity. Such an increase is also due to the particular habit of grazing animals, which do not tend to utilize the entire area but only the more suitable parts thus creating a heterogenic mosaic of microenvironments (high β-diversity).

However, in some environments this paradigm is not valid and grazing may constitute a disturbance event which entails processes of impoverishment and homogenization of vegetal communities, and, consequently, causes system imbalance (such processes can be irreversible and lead to rapid soil degradation and erosion; see for example Mysterud 2006). This is particularly true where the grazing history is short, for example in areas which have been recently colonized or invaded by wild animals, or where domesticated animals have been newly introduced by man or where wild animals have been introduced or reintroduced.

Grazing when started in areas which have not previously been involved, can represent a serious threat to native plant and animal communities and exerts heavy impacts on the ecosystem. For example, in forest environments, grazing can lead to a reduction of forest regeneration/renewal due to its particularly marked effects on newly germinated seedlings. In open areas (grassland and clearings), grazing can affect the entire plant community determining new competitive equilibria, benefiting rapidly regenerating or perennial species at annual species' disadvantage. Moreover, in such environments, grazing may allow entry of non-native species and consequently cascading effects caused by their competition with native ones.

Change in grazing regimes may also pose a threat to a particular site, since it may trigger mechanisms leading to alteration of local plant species diversity.

Sudden cessation of grazing activities may cause the establishment of new conditions in which there will be only a few dominant species. In such cases restoring the original grazing regimes, also employing domestic species (such as sheep, horses and cows) may turn out to be the most appropriate management strategy in order to maintain good heterogeneity degree and oppose/prevent impoverishment of species diversity.

Management techniques aimed at artificially restoring natural grazing regimes are properly reviewed in Ausden (2004). A key aspect of these management actions and strategies is to ascertain, for specific contexts, which are the optimal levels of grazing in relation to specific conservation goals (i.e., whether they are aimed at maximizing productivity and diversity of all species or only of target species).

Among anthropogenic disturbances, mowing with mechanical vehicles can result in community structuring which, apparently, is analogous to that caused by natural grazing, since, for example, it induces a decrease of herbaceous vegetation height. Actually, it should be noted that natural grazing produces a higher degree of environmental patchiness due to the fact that animals seemingly move about in a random manner, somehow lacking the regularity shown by mechanical mowing. Moreover, grazing cattle, with their excretions, causes accumulation of organic substance which, in turn, lead to soil enrichment and to increased invertebrate density (see also following paragraphs).

Digging and plowing activities: Digging by medium and large animals (such as carnivore mammals and ungulates) can exert substantial disturbances on topsoil and may indirectly affects plant communities. This activity can alter carbon:nitrogen ratio in the soil, favoring entry of new plant species which show ecological adaptations to the new conditions, and incrementing environmental heterogeneity at a larger scale (as in the case of the disturbed areas produced in grassland and forest areas by wild boars, *Sus scrofa*). At a different scale, disturbances produced by smaller organisms, often present at high densities, in ecologically suitable sites, are also remarkable. Noteworthy in this respect are certain bird species, like bee-eater (*Merops apiaster*) and kingfisher (*Alcedo atthis*); reptiles and meso-micro-mammals such as coypu (*Myocastor coypus*) and many other burrowing rodents (Fig. 7.2); insects, such as termites, ants, and other groups of Hymenoptera. These organisms by constantly digging below ground and on soil surface to forage and to build nesting sites, shift portions of soil thus facilitating passage of air and water as well as of other organisms. Animal modeled areas can represent an ecological opportunity

Fig. 7.2 An example of natural disturbance on soil components in mountainous dry grasslands (Festuco-Brometea). Small rodents, as voles (Microtidae), change the soil texture and porosity with implication on germination rate of single plants (here *Sideritis italica*; *Photo* Corrado Battisti)

Fig. 7.3 Feces of wild mammals contain nutrients affecting soil structure and composition (*Photo* Corrado Battisti)

which contributes to the establishment of new habitat patches for those species able to colonize dynamic and/or ephemeral environments (Eldridge and James 2009).

Soil plowing, conversely, is the activity performed by all those species which forage on surface soil layer: when intense and protracted over a short period of time it can lead to devastation of ground, while at low intensity and in the long term it can augment environmental heterogeneity creating opportunities for a high number of species, thus increasing biodiversity.

Deposition of feces and urine: Feces and urine, which are important components of the nutrient cycle, can increase nitrogen and phosphorus in the soil (Fig. 7.3). If deposited in freshwater basins they can cause eutrophication. As a consequence, nutrient increase stimulates the formation of a community characterized by lower species richness and populated by many weedy species.

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Chapter 8
Anthropogenic Threats

(…) humans are altering the planet
in diverse ways at ever faster rates

(Pressey et al. 2007)

…three years later, in Bangkok, I met Di Om-Koi, the chief forest ranger, to whom I asked how things were going with Wildlife Sanctuary management. His astonishing answer was: "Very well – I went up there last week and, when I left, everything was on fire!"

(Lovari 2012)

A thing is right when it tends to preserve
the integrity, stability and beauty of the biotic community.
It is wrong when it tends otherwise.

(Leopold 1949)

In the first section, our attention was focused on disturbances originated by natural agents having mechanical, physicochemical, and biological characteristics. In the following chapters, a fundamentally different class of events will be discussed, namely human-induced disturbances, which constitute a peculiar category of biological perturbations.

Although humans must be considered in every respect a biological agent, his technological skills, resulting from completely distinctive evolutionary history and cultural growth, when compared to other animal species, have had significant consequences on the ecosystems. Such consequences are so important and different in terms of their extent, duration, and intensity that they must be treated separately from those originated by natural phenomena and other biological organisms (Hobbs and Huenneke 1992; for Mediterranean context, see Blondel and Aronson 1999). In particular, Neolithic has been regarded as the period in which man's ability to transform environments underwent a steep increase (see also Diamond 2006[1] for possible explanations of such difference between *Homo sapiens* and other species).

[1]One of the first interdisciplinary analyses of the global consequences exerted by human-induced transformations is available in Thomas (1956). Although certainly dated, such an historical document, of extraordinary importance and originality, is perhaps the first to deal with this subject under different perspectives.

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Humans are ubiquitous and their ability to press and impact on the environment has reached such a level that at present they represent the dominant species in most terrestrial and marine ecosystems. The human species has extended his influence also in hostile contexts, such as the upper layers of the atmosphere, oceans, deserts, and polar regions, with measurable effects on species composition, density, biomass, and richness as well as on functional alteration of ecosystems themselves.

Human action on ecosystems has been the subject of ecological research for many decades, and since the 1970s, a new term has been coined, namely, 'stress ecology', indicating the discipline which deals with perturbation-induced alterations of environmental systems and particularly with those generated by human action (Barrett et al. 1976; Rapport et al. 1985).[2]

Human-induced disturbances (aka, *anthropic disturbances* or *threats*) can be extremely different, with respect to typology and regime, from the events caused by natural agents in the strict sense. In particular, the different intensity and spatial–temporal articulation characterizing human-induced perturbations may prevent organisms from showing appropriate eco-behavioral and adaptive responses. This may hamper their survival and consequently the medium- and long-term vitality of populations, communities, and ecosystems.

Alteration of natural disturbance regime as well as high-intensity anthropic disturbances are the main causes of the drastic and irreversible reduction of environmental system complexity and resilience. Reduction of complexity leads to simplification and this, in turn, decreases ecosystem resilience towards subsequent events (Farina 2006). Moreover, according to principles of environmental economy, anthropic disturbances may entail a reduction of ecosystem natural capital, in terms of their commodities and services (De Groot et al. 2003).[3]

Anthropogenic disturbances can either directly or indirectly act at any spatial and temporal scales. In fact, they depend on factors and circumstances, characteristic of territorial contexts related to historical, political, economical, cultural, and social arenas. They can act differently on composition, structure, and function of the

[2]One of the most important goals of stress ecology is defining the so called 'ecosystem-level distress syndrome'. Such a syndrome manifests itself in the ecosystems following a perturbation which induces a change in nutrient cycle, productivity, and frequency of dominant species. It is also capable of producing dominance shift among species (from those characterized by large size and a relatively long life cycle to the opportunistic species, having reduced size and short life cycle; Barrett et al. 1976).

[3]With regard to this subject, a 'Capital Natural Index' (CNI) has been defined, ranging between 0 and 100 % (compare De Groot et al. 2003). Such authors have also introduced the notion of "bearing capacity" indicating the existence of a threshold beyond which environmental systems cannot be any longer utilized or stressed. Such capacity depends on ecosystem type and features (resistance, resilience, sensitivity), site history (compare Swetnam et al. 1999), and disturbance type. According to this approach, natural capital is critical if (i) the ecosystem is particularly important (from an ecological, socio-cultural and economic point of view) and if (ii) the degree of threat is high. This latter parameter can also be indirectly measured considering the changes in quantity and quality of an ecosystem's residual natural capital.

affected ecosystems. In many cases, different anthropic disturbances on the same natural system can overlap and show synergic action, thus modifying, even heavily, the characteristics of the system itself and triggering feedback mechanisms and cascading events (Fig. 8.1).

In this respect, numerous examples can be considered. Tropical deforestation can impact on some frugivorous and nectarivorous bird species reducing their density at local scale and yielding important ecological consequences. In fact, as these birds contribute to the dispersal of seeds, pollen, and nectar during their migration, destruction, degradation, and fragmentation of tropical forests can trigger cascading consequences on plant species distribution and density patterns, even at a great distance from the event (Mace et al. 1998; see also Battisti and Romano 2007 for other examples on fragmentation-induced cascading effects).

Research conducted on passenger pigeons (*Ectopistes migratorius*; see Ellsworth and McComb 2003) constitute a remarkable case in point. This species, now extinct

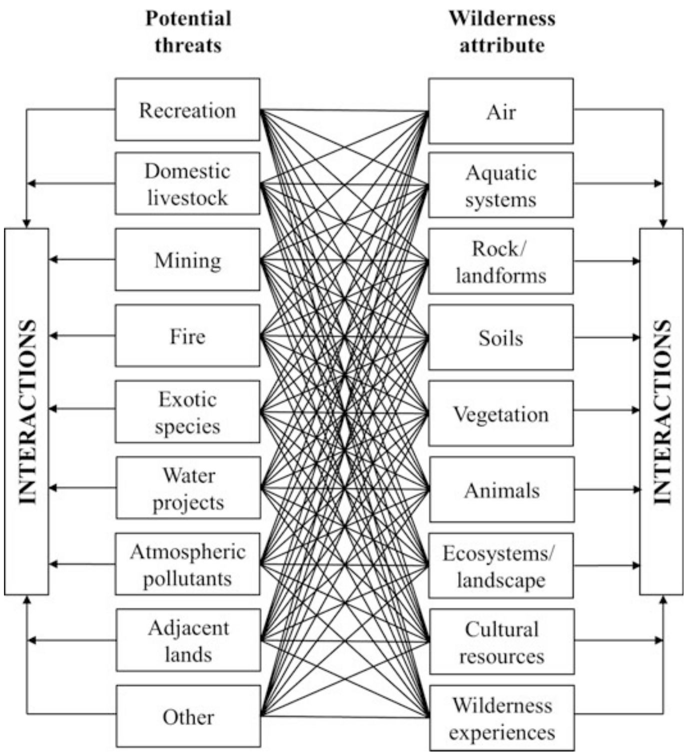

Fig. 8.1 Linkages between potential threats and the wilderness components they may impact. Threats and components can interact with complex modalities (interactions, positive and negative feedbacks, cascading mechanisms; from Cole 1994)

but extremely abundant in the past, was capable of migrating and aggregating in roosting sites which included millions of individuals. It has been demonstrated that, without human interference, such species represented a powerful regulative factor favoring the spread of some of the main tree species of northwestern United States forests. Upon the passenger pigeon's sudden extinction, mainly as a consequence of undiscriminating hunting activities, such forests underwent a transformation in composition and vegetal species dominance, which has been directly ascribed to the variation of the natural disturbance regime represented by this bird.

Another example of a 'cascading' effect induced by anthropic disturbances concerns large predators. Their direct persecution (through shooting) produces alterations of food chains (increase of prey species, meso-predator release effect, with a consequent impact on food chain at lowest levels).

In some cases, anthropic disturbances can occur according to different modalities. In this respect, threats can be distinguished as 'all or nothing' like those constituted by infrastructures (roads, artificial canals, power lines) which, once collocated in a site, represent a source of stable and permanent threat. Other types of threats manifest themselves along a gradient, acting in a gradual manner, according to a range of variations of certain parameters which is articulated over time (for example, hydric stress induced by variation of water regime, trampling, direct persecution of animals). In general, politics and conservation projects aim at preventing 'all or nothing' threats and mitigating 'gradient' threats (Salafsky et al. 2003).

Knowing type and regime of human-induced events allows the definition of appropriate strategies and management measures aimed at mitigating or eliminating their impact on ecosystem components and ecological processes. For this reason, over the last decade a specific branch of conservation biology, named 'threat analysis', has been developed. Such a branch is characterized by its own terminology, theoretical framework, and principles. It aims at standardizing concepts, methodologies, and operational procedures, to allow information, systematization, and comparison in a technical and scientific way, and to facilitate the definition of effective actions.

Threat analysis has been applied to evaluate the causes of threats to single species facing extinction (species-based approach) and constitutes part of the methodological aspects of Red Lists (see IUCN Red Listing—www.redlist.org, for further information on the subject). In this book, threat analysis in relation to overall territorial contexts and sites considered as reference units, will be briefly discussed ("site-based" approach; Salafsky et al. 2003, 2008). However, such distinction has only a theoretical value and, in many instances, both approaches can be utilized in the same context and in a complementary manner.

Threat analysis definitions and terminology are partly derived by the more comprehensive subject of risk assessment, pertaining to different disciplines. This can make concepts unclear and hamper their comprehension since terminology refers to different languages. Therefore, as far as threat analysis is concerned, a fundamental starting point is language standardization, as already happens for other applied and fundamental sciences. Clear, specific and shared language can be useful at facilitating the description of observed phenomena as well as exchanging information among practitioners even from different backgrounds. Moreover, it can be helpful for a more efficient strategy definition and allocation of available financial resources.

One of the first important documents on threat analysis and the necessity of its standardization has been proposed at the beginning of the 2000s (Salafsky et al. 2003). In this paper, a great deal of aspects related to terminological definition of conservation concepts, taxonomical nomenclature,[4] and hierarchical ordering of the events has been discussed. Moreover, the author also proposed a quick quantification of the events and finally their comparison and spatial mapping.

First of all, Salafsky and colleagues have remarked that terms referring to threats should be: (i) *clear*: terms and their relationship to one another need to be unambiguous and precise in their definitions; (ii) *understandable*: terms need to be used in accordance with their general meaning in the ordinary language and therefore they need to be understandable to the wide public; (iii) *compatible*: terms need to be compatible with the vocabulary currently being used by various conservation organizations.

Therefore, as far as human-induced events are concerned, the following general terms and definitions have been proposed (for further readings, see TNC 2006; Salafsky et al. 2008):

– Threat: any human activity or process that has caused, is causing, or may cause the destruction, degradation, and/or impairment of biodiversity and natural processes (Salafsky et al. 2003).[5] Another definition describes threats as: human activities or the consequences of human activities that have the potential to change conditions of specific environmental components (Cole 1994). According to such definitions, threats are, therefore, agents (or 'pressures')[6] which are capable of inducing changes. Such pressure-induced changes in environmental components constitute a state variations of the system and, when they are detrimental to its composition, structure, and function, can be defined as 'impacts'.

The previous two definitions of threat are quite different. According to Cole (1994) threat is any event capable of producing changes, whereas Salafsky and

[4]As mentioned by Salafsky, taxonomy and systematics of anthropic threats are equivalent to the Linnean system of classification of living organisms used in biology, or to Mendeleev's periodic table of elements used in inorganic chemistry.

[5]As pointed out by Salafsky et al. (2003), in ordinary language, threat indicates an expression of intention to inflict evil, injury, or damage implying that threats can only occur in the future (online Merrian Webster Dictionary). However, the 3rd Edition of the Shorter Oxford English Dictionary defines threat as "painful pressure, oppression, compulsion; vexation, torment; affliction, distress, misery; danger, peril" indicating that threats can occur both in the present and future.

[6]A synonym of threat is therefore pressure. This is widely used in the literature concerning EU Habitats and Water Framework Directives, in international conventions (e.g. Ramsar) as well as in DIPSIR model.

colleagues (2003) underline that such changes must be capable of causing observable events (destruction, degradation, impairment). In order to conduct an appropriate threat analysis, it is necessary to understand when an anthropic event can actually constitute the subject of management interest.

Every threat event can be subdivided into two components: a factor or process which starts the event itself (source) and a consequent process (the action in itself or the mechanism, Balmford et al. 2009). However, on this aspect a general consensus is lacking and other authors regard threat both as the change-producing agent and the change itself.

In a more restricted and operational context (exclusively connected to territorial policies and to the policies concerning land-use changes) in the WCS document, threats have been defined as land-use practices and policies that have direct or indirect effects on the species or habitats that we want to conserve. Finally among other definitions, Wilson et al. (2005) regard a threatening process as an event which can threaten abundance, vitality, and evolutionary processes of a given species.

Threat concept is often used as a synonym with direct threat and underlying causes, as briefly discussed below. Two causal levels of threats have been identified

– direct threats (synonyms: source of stress, proximate features, proximate threats): are constituted by activities, factors and processes which cause, have caused or are likely to cause an impact or a direct stress on biodiversity targets, physically causing their integrity alteration, destruction, or degradation on the short-, medium- and long-term. Direct threats can also be distinguished as 'internal direct threats' if due to human activities which are internal to the site under study, and 'external direct threats' if due to external human activities. Mostly, such direct threats are identifiable at local and regional scales, at least in conservation planning (Pressey et al. 2007). They are the local expression of indirect threats (ultimate threats, according to Pressey et al. 2007) the latter being constituted by geological, ecological, and environmental factors which can be highlighted at a larger scale (Lambin et al. 2001).[7]
– indirect threats or driving forces (underlying causes; drivers; also defined as ultimate threats or root causes): They constitute the range of conditions (historical, social, economical, political, demographical, and cultural) connected to the anthropic features of a site which allow or contribute to the presence and persistence of one or more direct threats. Usually, behind each direct threat, a sequence of causes can be detected. In many instances, it can lead to the identification of specific indirect threats or driving forces.

[7]In conservation planning, this author also mentions the concepts of expanding threats, contracting threats, and threat as spatial-temporal mosaic.

Sometimes the distinction between direct and indirect threats may be problematic. In general, direct threats can be considered as factors/processes which are proximate to a given target, alter its key ecological attributes, KEA)[8] and produce stress. Factors/processes which are less proximate can be considered indirect. Since threats are time-linked processes not only limited to the short-term, other definitions can be proposed which take into account their temporal collocation. Threats can be thus distinguished as (i) past threats; threats which occurred in the past and cease to operate/be effective in the present (even though they can still affect the targets); (ii) current threats; threats which are currently acting on the site; (iii) future threats; threats which are not currently acting on the site but are likely to be effective in the future. In any case, the same event can be considered as a direct or indirect threat depending on the context or target on which it exerts its action.

– stress: In threat analysis stress is the damage, degradation, or alteration of the conservation target KEA (see above). Such change can also reduce target integrity. Examples of stress acting on a given KEA include the following: reduction of reproductive success, increase of mortality rate, reduction of dispersal ability of an animal population, deterioration of water quality, fragmentation degree of a given habitat type, decrease of species richness. A KEA, affected by a stress subsequent to a threat, can become degraded (degraded key attribute).

Stress must not be confused with threat. It represents the response to a target altered condition produced as a consequence of a threat. It can be said that a direct threat has manifested itself only when a target component has been affected by an identifiable and measurable stress. Some of the systems (EPA 1998; TNC 2006) employed in threat analysis have made a distinction between source of stress, equivalent to the concept of direct threat, and stress in the strictest sense of the word. The definition of specific stresses requires a thorough analytical approach, so that the team members may be compelled to make extra research efforts with expenditure of energy and resources. Therefore, at least in some cases, quantification of stress level can be omitted by having it be implicit in the relation linking the threat to the target.

– target (synonyms: biodiversity targets, conservation targets, focal targets, biodiversity features): In the causal relation threat-environmental components, we will refer to 'target' as the target environmental component (i.e., a biological or ecological entity: population/species, community, or ecosystem) or process on which the threat displays its effect, which are impacted, and which conservation

[8]There are some examples of KEAs related to given targets. Population density, biomass, reproductive success, birthrate and mortality rate, dispersal rate (in this case the target is the population of a given species); species number/richness, diversity, evenness (in this case the target is a given community); size of an ecosystem function (in this case the target is a given ecosystem). KEAs allow the definition of the state of a target component in a given time-point.

and management strategies are focused on.[9] As previously mentioned, the target status is defined by its key ecological attributes (KEAs).

The above-mentioned terms are utilized in conservation and management projects aimed at eliminating or mitigating the threats acting on specified targets. Thus, we deemed useful to offer a list of the terms connected to the planning process, which are also extensively utilized throughout the book. The list follows the indications given in Margoluis and Salafsky (1998) and Salafsky et al. (2002, 2008).

- Project: It is any set of actions undertaken by any group of managers, researchers, and organizations interested in achieving certain defined objectives. Numerous guidelines can be found in specific literature and on the Internet which allow project definition and planning. One of these is called Logical Framework Approach (LFA: Jackson 2000) in which the most important stages of project designing are synthesized. In its general formulation, two three-step phases are considered in LFA. The *analysis phase* is dedicated to dealing with (1) *problems*, by making the so-called tree problem, following a hierarchical conceptual scheme based on cause-effect relationship; (2) *objectives*, by making, according to a conceptual scheme the objective tree; (3) *strategy*, by grouping the objectives in agreement with the desired outcomes. Moreover, to assess the project basic assumptions a range of conceptual tools can be employed. Among them, *Intent structure analysis*, *Force field analysis*, *SWOT* (*Strengths*, *Weaknesses*, *Opportunities*, *Threats*) analysis. The latter explores project constraints and opportunities, comparing strengths and weaknesses internal to the project, to opportunities and threats external to it. Subsequent to the analysis phase, there is a *planning phase* during which logic foundations are developed in order to define *objectives*, *actions*, and *expected outputs*, identifying *indicators* and writing records/files containing *activities*, *costs* to be supported and *time* needed.
- objective: *it represents the actual outcome to be achieved through the application of project actions*. Objectives are the pillars on which projects are built and their enunciation in planning procedures represents a pivotal step. A well-defined objective must meet the following criteria. It must be *impact-oriented* (sensitive to it), *measurable*, *limited in time*, *specific*, *practical*. Moreover, an objective must also be defined by: *action* (e.g., restoration), *timescale* within which it has to be carried out, (e.g., by 2016), *space* and *site* involved (e.g., the context at a given scale), range of change (e.g., 30 %), the *target* involved (e.g., rush-beds), and the *attribute* of the target involved (e.g., density or surface coverage).

[9]One example is constituted by the categories of the IUCN Red List which evaluate the status of the targets represented by threatened species by considering key attributes like density and population size. Similarly, BirdLife International evaluates the status of sites which are relevant for protecting target species of birds through a scoring system which synthetically expresses the status conditions of a few key attributes: for example the cover of suitable habitat (condition score, BirdLife International 2006).

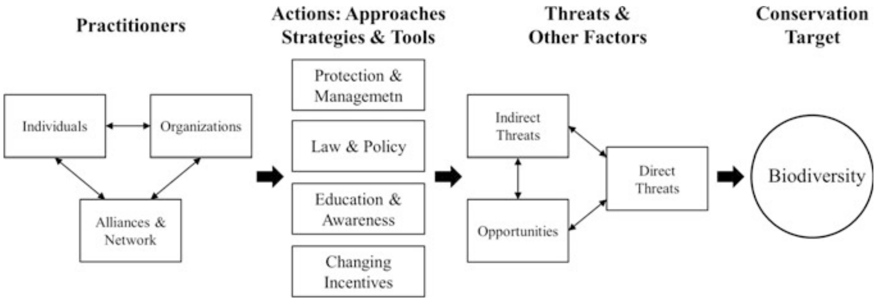

Fig. 8.2 Simplified schematic representation of the relationship between professionals belonging to the project team, actions, threats and targets (from Salafsky et al. 2002)

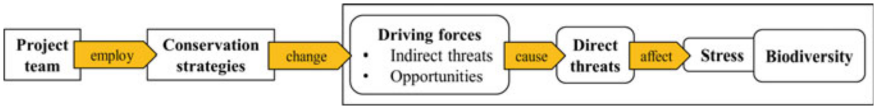

Fig. 8.3 General pattern of a conservation project. Conservation actions can be applied to driving forces, direct threats, and also to biodiversity targets. For further definitions, see text

- conservation actions: *comprise the interventions or activities carried out by the project team and aimed at fulfilling the conservation objectives*. Well-defined actions and activities within a project must be: related to the objective, focalized, achievable, and appropriate to the context. They can be applied to driving forces, direct threats, or targets themselves. Often ‘action’ and ‘activity’ are utilized as synonyms with other terms (such as intervention, response, measure, approach).
- project team: it consists of a *group of people (technicians, practitioners, researchers, administrative staff) committed to define, implement, manage, and monitor a conservation project* (Figs. 8.2 and 8.3).

Threat Analysis: A New Discipline

Alteration of natural ecological regimes is the primary subject on which practitioners in charge of a conservation project focus their attention. However, to date, a reasoned and consistent analysis of such events is not common practice among project teams.[10]

[10]Drawing a comparison with medical sciences, what has been lacking or quite defective, to date, is the *diagnosis* and the study of threat *pathology*. Therefore, even though threats have been identified in conservation processes, they have not been approached with the same tools as those employed in medical sciences.

When managing a site relevant to conservation or when defining specific conservation strategies for specific targets, it is important that ongoing threats be identified, named, and classified. Their regimes, as well as the targets on which they act and the stresses which affect the targets as a consequence of the threats, also need to be carefully evaluated. Comparison of threat regimes and assessment of the effects on targets may enable practitioners to define the action priorities needed to fulfill the objectives optimizing the available resources.

Understanding the anthropogenic events occurring in a site is the main step towards an approach which considers threats in the appropriate way. It is also important to verify whether they can be considered real threats acting on certain natural components of relevant ecological and conservational concern. Knowing threat typology and regime can therefore allow the definition of appropriate strategic actions aimed at mitigating threat impact on specific environmental components.

Over the last decade, on the basis of such assumptions and considerations, a new discipline, named threat analysis, has been developed. In fact, information shared among various international organizations has allowed the acquisition of a standardized approach system. This field has thus become a specific branch of conservation, characterized by its own theoretical basis and particular tools. Some of these organizations (among which: IUCN, TNC, WWF) has developed a standardized system in order to define, name, and quantify threats. However, at least in the initial phase, a universal shared system was lacking and the approaches differed among one another. This has caused and still can cause a problem along the various steps of the conservation process, among which are priority choice, planning of most effective programs and strategies, measurement of target conservation status.

Recently, a revision of the various approaches has been done, aimed at defining a universal standardized system (Salafsky et al. 2003). In this paper, aspects related to concept terminological definition, *taxonomy* (nomenclature), and *systematical classification* (hierarchy) of threats, as well as their quantification, have been considered. Moreover, the possibility of their *comparison* and *mapping* has been discussed. WWF, within WWF Standards of Conservation—Project and Programme Management (PPMS: WWF 2012)[11] has also developed a procedure of threat rating and ranking (Standard step n° 1.4). This has enabled the creation of a unified system which can be constantly updated and implemented with requirements and experiences made in the field by various experts. Moreover, in order to allow a wider spreading and sharing of the application tools and outcomes, a collaboration among many conservation organizations has been started. They have shared many experiences, creating the Conservation Measures Partnership (http://www.conservationmeasures.org).

[11]With '2012' we refer to the last available update available on the site http://wwf.panda.org/what_we_do/how_we_work/programme_standards.

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Chapter 9
Nomenclature and Taxonomy of Threats

There is no ideal classification system that perfectly models the complexities of the myriad situations that are facing conservation practitioners

(Salafsky et al. 2009)

Conservation biology is an action-oriented scientific discipline. Practitioners in this field need to utilize a standard terminology which allows clarification of the concepts involved, information acquisition, and quick sharing/transfer of the experiences (Pullin and Stewart 2006). However, at least until the end of 1990s, lack of a standardized system has caused considerable methodological confusion in the field of threat analysis. Still, today in many conservation projects (i) different names are given to the same threat typology, (ii) threats are confounded with *driving forces*, *impacts*, *pressures*, and *stresses*. In this way, complex economic activities, single events of anthropic origin, and the effects of such impacts on organisms are put on the same ground. For example, agriculture is a *driving force,* phytochemicals are specific disturbance/*threat* events which exert pressures on certain *targets* (e.g., sensitive plant species and insects). The latter are *impacted* and the physiological changes occurring in plants and insects as a consequence of chemical usage are *stresses*.

Lack of a standardized nomenclature system, particularly when dealing with technical and scientific subjects, may create confusion and problems when different projects are compared to one another. This, in turn, hampers experience exchange and realization of adaptive management and monitoring processes. Moreover, without a standard nomenclature, a classification system for threats, which allows us to group them into categories according to a similarity criterion, is unattainable. A valid nomenclature and classification system for threats should be characterized as follows (see Salafsky et al. 2003):

(i) *hierarchical*, structured according to homogeneous categories following a hierarchical order. In such a way, recognition of similarities among the main characteristics of the various threats will be facilitated.

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Environmental Science and Engineering, DOI 10.1007/978-3-319-32476-0_9

(ii) *universal and inclusive*, i.e., applicable to every context and thus comprising the entire range of possible and ongoing threat events, at least at the highest hierarchical levels (main categories, or families, of threats).
(iii) *consistent*, i.e., all threats in the same hierarchical level should be attributed to the same typology (because they show similarity).
(iv) *expandable*, so as to enable classification updating by adding new categories or single threat events.
(v) *exclusive*, every threat is characterized by its own nomenclature and it cannot occupy more than one position within general classification.
(vi) *multi-scaled*, i.e., characterized by one nomenclature which applies to any site and scale.

Recently, a few different nomenclatures and classification systems have been proposed by international organizations. The most recent are the IUCN–CMP (International Union for Conservation of Nature and Conservation Measures Partnership) system developed in June 2006 on the basis of a preliminary work by Salafsky et al. (2003; subsequently implemented and published in the scientific journal "Conservation Biology"; see Salafsky et al. 2008 and CMP 2005) and the system presented in Appendix E of the European Commission (EC) Natura 2000 Standard Data Form.[1]

A first revision of the current nomenclature, with enclosed taxonomic system, was undertaken in 2003 by Nick Salafsky and colleagues who focused their attention solely on *direct threats* without considering *indirect threats* and *driving forces*. These authors have reviewed the various nomenclature and classification systems which we synthesize as follows:

- EPA (1998). This system represents one of the first attempts to arrange *events* and *targets* in a logical way. It includes a working definition of *assessment endpoints* (i.e., target ecological components such as species, communities, ecosystems), together with their specific attributes (e.g., reproductive success, density, etc.), and sources (i.e., entity or actions which generate chemical, physical, or biological stressors). Stressors are impact-generating factors, with impact considered as a measure of the effects on the assessment endpoints.[2]

[1]The list of pressures and threats compiled by EC (updating 18.11.2009, reporting group, and 16.3.2011) contains more than 200 types of pressures, threats, and activities subdivided into the following major categories: A. Agriculture; B. Forestry; C. Mining, extractions of materials, energy production; D. Transportation, service routes; E. Urbanization, human habitations, commercial areas; F. Use of biological resources (not Agriculture, neither Forestry); G. Human intrusion and disturbance; H. Pollution; I. Invasive and/or problematic species and genes; J. Alteration of natural systems; K. Biotic and abiotic natural processes (catastrophes not included); L. Geological events and natural disasters; M. Climatic changes; X. No threats or pressures; U. Unknown threats or pressures.

[2]According to Barrett et al. (1976), stressor is an internal or external perturbation applied to a system.

- TNC catalog of threats. Gershman (2000) compiled a list of threats from 90 TNC conservation sites. He then provided a hierarchical taxonomy of both stresses and sources of stress.
- TNC 5-S Framework (TNC 2000). It is an auxiliary methodology used in conservation planning of specific sites. Initially, it entails a description of the *systems* (synonymous with *conservation targets*) which the project is focused on (single species, communities, ecosystems) and is characterized by specific *key ecological attributes* (*KEA*). Conservation targets are affected by stresses which alter KEAs. Stresses, in turn, are caused by factors or processes defined as sources of stress. The document contains the description of two lists of stresses and stress sources even though they are still incomplete.
- WWF analysis of root causes (Stedman-Edwards 1998; Wood et al. 2000). It is a systematic revision suggesting a synthetic nomenclature of the main categories of *root causes/proximate causes*, which globally impact biodiversity.[3]
- WWF Framework (WWF 2000). This document deals with threats, defining and disentangling major issues along the causal relation threat-target (stresses, pressures, root causes).
- Foundation of Success (FOS) taxonomy of direct threats (Salafsky et al. 2002). In this paper, *target* is defined as the bioecological object which conservation project is focused on. Target is affected both by direct threats (which are in immediate relation to the target) and by indirect threats (those acting on direct threats). *Opportunities* are events which positively affect targets (positive impact), *threats* are events which negatively affect targets (negative impact). A table containing a classification of direct threats related to large geographical areas (e.g., biomes) is also shown. However, in this paper a clear distinction between threats and stresses is not clearly stated.
- WWF-RAPPAM approach (Ervin 2002). It deals with a method aimed at the effectiveness evaluation of protected areas situated, for example, in a given region. It also offers an overview of biodiversity status, pressures (i.e., activities which negatively affected target integrity) and threats which are potential or

[3]These are: (1) habitat loss and alteration; (2) over-exploitation of biological resources; (3) introduction of non-native species; (4) pollution in its various forms; (5) climatic changes. Such threat categories, in turn, can be unified into three major categories which are deemed responsible for the current global biodiversity crisis (Mace et al. 1998), namely: (1) habitat destruction and degradation (it also includes pollution and environmental fragmentation); (2) overexploiting of biological resources; (3) invasion of non-native species. Auld and Keith (2009) have proposed another taxonomy which subdivides threats in 5 major groups: (1) habitat destruction/degradation; (2) climatic changes; (3) destruction of biological interactions; (4) change of disturbance regime; (5) over-exploitation of native species. Similarly, Diamond (1989, 2006) speaks about the “evil quartet”, quoting: (1) habitat destruction; (2) direct persecution (e.g. hunting, fishing); (3) introduction of new species; (4) species extinction waves (cascading effects) unfolding on communities and ecosystems.

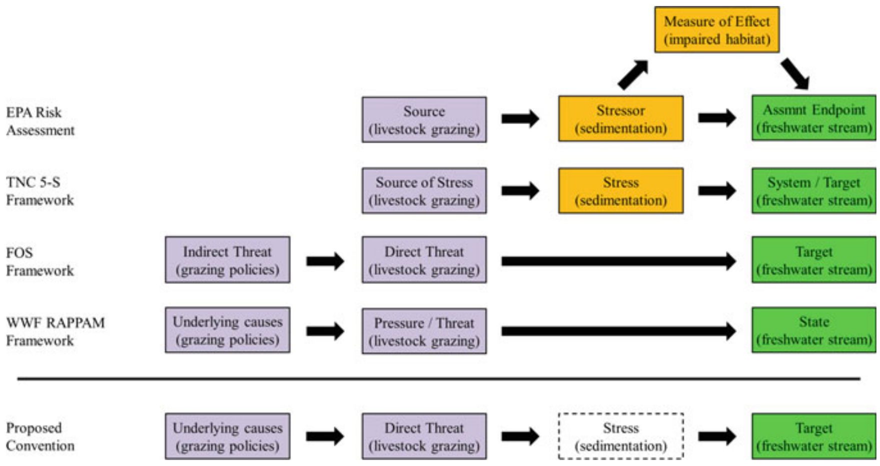


Fig. 9.1 Causal relations and corresponding terminology according to the different approaches (see text). Examples have been reported in the *boxes* (from Salafsky et al. 2003)

imminent pressures.[4] *Underlying causes* act *before* pressures and threats. Such an overview is helpful to define objectives.

A schematic representation of the causal relations and terminology proposed in the different approaches is given in Fig. 9.1 (from Salafsky et al. 2003).

On the basis of their revision, Salafsky et al. (2003), besides highlighting the terminological confusion which affects the subject, have proposed a single conceptual model (*causal chain*) and a unifying nomenclature with three hierarchical levels (family or category, genus, and species of threats). Other proposals concerning nomenclature, threat classifications and corresponding conservation actions are available in WCS (2002), AWF (2003), CMP (2004, 2005) IUCN (2005a, b), Balmford et al. (2009). Margoluis et al. (2009) also offer a useful description of how conceptual models of this kind can be compiled (see Fig. 9.2).

Therefore, in the first classification that has been proposed, the following categories (or families) of direct threats have been reported (Salafsky et al. 2003):

– *habitat conversion*, i.e., all those factors or events which are capable of causing loss and destruction of natural systems (habitat types)[5];
– *linear infrastructures*, comprising the entire range of different technological corridors utilized to carry people, wares, energy and the corresponding processes or mechanisms;

[4]In this and other approaches (for example that utilized by Italian Ministry of Environment) *pressure* and *threat* are considered as distinct concepts.

[5]Habitat here indicates ecosystems or plant associations (as it does in English specific literature and also in EU Habitats Directive, 92/43/CE).

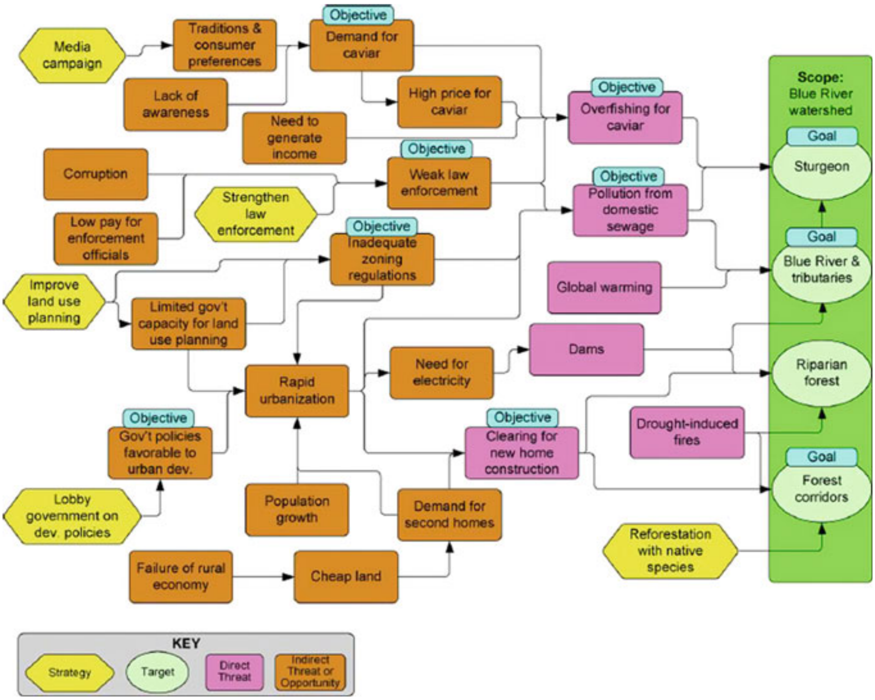


Fig. 9.2 An example of conceptual model with target, direct threats, indirect threats and strategies. Objectives are also reported (from Margoulis et al. 2009)

Fig. 9.3 An example of urban sprawl (threats 1.1—Housing and urban areas and 4.1—Roads and railroads; *source* Atlanta, Georgia, USA; Google Earth 2015)

Fig. 9.4 A secondary montane dry grassland (Festuco-Brometea) grazed by horses in Apennines (central Italy; threat 2.3—Livestock farming and ranching) represents a landscape matrix where wooded patches are of anthropogenic origin (planted coniferous trees, mainly *Pinus nigra*; threats: 8.1—Invasive non-native/alien species and 8.3—Introduced genetic material). A windfarm, as a source of renewable energy is also present (threat 3.3—Renewable energy): these infrastructures (especially if located along mountain ridge) are a pressure factor on migrant birds and bats that may collide with windmills or induce a habitat change (*Photo* Corrado Battisti)

- *use of abiotic resources*, related to all factors, processes and mechanisms pertaining to the extraction of non-biological resources;
- *non-destructive use of biological resources*; comprising the events aimed at harvesting and utilizing biological resources without exploiting them irreversibly and in an unsustainable way;
- *pollution*; comprising all factors, processes and mechanisms which lead to human-mediated introduction and diffusion of substances and energies not belonging to the ecosystems. For example, chemicals, biochemical and thermal products, radiation, noise, including both point and non-point sources of pollution.
- *invasive species*; comprising all factors, processes, and mechanisms leading to human-mediated introduction, colonization, diffusion, and/or invasion of animal vegetal, and pathogenic organisms coming from different ecosystems or regions (alien species). Invasive organisms can also belong to native species which are

Fig. 9.5 Many threats are linked to energy production (3.1—Oil and gas drilling; 9.2—Industrial effluents as toxic chemicals; Perelli industry, Piombino, Tuscany, central Italy, near the Orti-Bottagone WWF protected area, a marshland of high conservation value; *Photo* Corrado Battisti)

Fig. 9.6 The extractive activities, exploring for producing minerals and rocks, act as an irreversible resource consumption, disrupting the underwater regime (hydrogeological effects), the structure and composition of soil and vegetation (threat 3.2—Mining and quarrying; *Photo* Corrado Battisti)

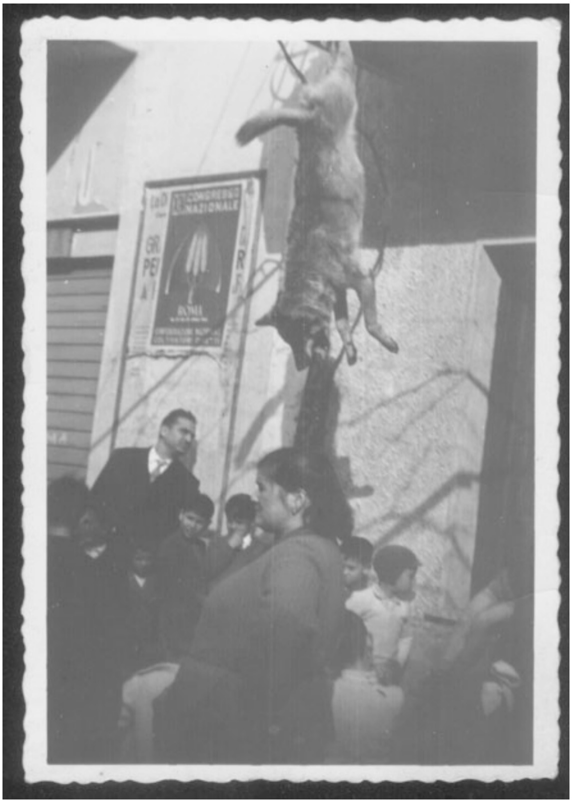


Fig. 9.7 A historical image (about 1962–1963) of one of the last individuals of wolf (*Canis lupus*) killed in Lepini mountains (Italy) (threat 5.1—Hunting and collecting terrestrial animals) (from Spartaco Gippoliti)

problematic (e.g., generalist synanthropic species). Other threats, directly caused by these species, are also included in this category.

– *modifications of natural processes and disturbance regimes*; comprising all factors and mechanisms causing changes in natural disturbance regimes.[6]

In the first version of Salafsky and colleagues' nomenclature system (2008, version 1.1), the highest taxonomic level (first level) was represented by threat *category* followed by a second level (analogous to the genus level used in biological taxonomy). Since anthropogenic events, which may locally occur on the

[6]Other classifications have been proposed, which change according to the criteria chosen to define categories.

Fig. 9.8 Coppice management is a historical practice carried out in Mediterranean landscapes (threat 5.3—Logging and wood harvesting). This periodical activity include other several anthropogenic disturbances (motor-vehicle transit, noise, human frequentation) affecting many ecosystem components (Mount Soratte nature reserve, central Italy; *Photo* Corrado Battisti)

planet, are highly heterogeneous, naming the third level (corresponding to the threat *species*, taking place locally) has been considered an open issue by these authors who have only offered a few illustrative examples.[7]

Nomenclature and taxonomy according to IUCN–CMP has been reported in Table 9.1 (levels 1 and 2; IUCN–CMP 2012). Nomenclature and taxonomic system is being constantly revised and therefore we suggest that updates available on the Internet be checked regularly.

Naming particular threats or assigning them to a given category or hierarchical level may prove quite difficult at times (see Salafsky et al. 2008, for examples). For this reason, further information and instructions are provided on IUCN website. This enables readers and authors of classification systems to exchange information and opinions.

[7]In a few cases, a third level has been defined by groups of specialists working on particular subjects (for example on inland waters and marine environments).

Table 9.1 United classification of direct threats—synthesis of families (taxonomic level 1) and genus (level 2)

Direct threat (threat family: level 1 and genus: level 2)	Definition
1. Residential and commercial development	Threats from human settlements or other non-agricultural land uses with a substantial footprint
1.1 Housing and urban areas	Human cities, towns, and settlements including non-housing development typically integrated with housing (Fig. 9.3)
1.2 Commercial and industrial areas	Factories and other commercial centers
1.3 Tourism and recreation areas	Tourism and recreation sites with a substantial footprint
2. Agriculture and aquaculture	Threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture and aquaculture
2.1 Annual and perennial non-timber crops	Crops planted for food, fodder, fiber, fuel, or other uses
2.2 Wood and pulp plantations	Stands of trees planted for timber or fiber outside of natural forests, often with non-native species
2.3 Livestock farming and ranching	Domestic terrestrial animals raised in one location on farmed or non-local resources (farming); also domestic or semi-domesticated animals allowed to roam in the wild and supported by natural habitats (ranching) (Fig. 9.4)
2.4 Marine and freshwater aquaculture	Aquatic animals raised in one location on farmed or nonlocal resources; also hatchery fish allowed to roam in the wild
3. Energy production and mining	Threats from production of nonbiological resources
3.1 Oil and gas drilling	Exploring for, developing, and producing petroleum and other liquid hydrocarbons (Fig. 9.5)
3.2 Mining and quarrying	Exploring for, developing, and producing minerals and rocks (Fig. 9.6)
3.3 Renewable energy	Exploring, developing, and producing renewable energy (Fig. 9.4)
4. Transportation and service corridors	Threats from long narrow transport corridors and the vehicles that use them including associated wildlife mortality
4.1 Roads and railroads	Surface transport on roadways and dedicated tracks (Fig. 9.3)
4.2 Utility and service lines	Transport of energy and resources
4.3 Shipping lanes	Transport on and in freshwater and ocean waterways
4.4 Flight paths	Air and space transport
5. Biological resource use	Threats from consumptive use of “wild” biological resources including both deliberate and unintentional harvesting effects; also persecution or control of specific species

(continued)

Table 9.1 (continued)

Direct threat (threat family: level 1 and genus: level 2)	Definition
5.1 Hunting and collecting terrestrial animals	Killing or trapping terrestrial wild animals or animal products for commercial, recreation, subsistence, research or cultural purposes, or for control/persecution reasons; includes accidental mortality/bycatch (Fig. 9.7)
5.2 Gathering terrestrial plants	Harvesting plants, fungi, and other non-timber/non-animal products for commercial, recreation, subsistence, research or cultural purposes, or for control reasons
5.3 Logging and wood harvesting	Harvesting trees and other woody vegetation for timber, fiber, or fuel (Figs. 9.4 and 9.8)
5.4 Fishing and harvesting aquatic resources	Harvesting aquatic wild animals or plants for commercial, recreation, subsistence, research, or cultural purposes, or for control/persecution reasons; includes accidental mortality/bycatch that include nutrients, toxic chemicals and/or sediments
6. Human Intrusions and Disturbance	Threats from human activities that alter, destroy and disturb habitats and species associated with non-consumptive uses of biological resources
6.1 Recreational activities	People spending time in nature or traveling in vehicles outside of established transport corridors, usually for recreational reasons (Figs. 9.9 and 9.10)
6.2 War, civil unrest and military exercises	Actions by formal or paramilitary forces without a permanent footprint
6.3 Work and other activities	People spending time or traveling in natural environments for reasons other than recreation or military activities
7. Natural system modifications	Threats from actions that convert or degrade habitat in service of "managing" natural or semi-natural systems, often to improve human welfare
7.1 Fire and fire suppression	Suppression or increase in fire frequency and/or intensity outside of its natural range of variation (Fig. 9.11)
7.2 Dams and water management/use	Changing water flow patterns from their natural range of variation either deliberately or as a result of other activities (Fig. 9.12)
7.3 Other ecosystem modifications	Other actions that convert or degrade habitat in service of "managing" natural systems to improve human welfare (Fig. 9.9)
8. Invasive and other problematic species and genes	Threats from non-native and native plants, animals, pathogens/microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance
8.1 Invasive non-native/alien species	Harmful plants, animals, pathogens and other microbes not originally found within the ecosystem(s) in question and directly or indirectly introduced and spread into it by human activities (Fig. 9.13)

(continued)

Table 9.1 (continued)

Direct threat (threat family: level 1 and genus: level 2)	Definition
8.2 Problematic native species	Harmful plants, animals, or pathogens and other microbes that are originally found within the ecosystem(s) in question, but have become "out-of-balance" or "released" directly or indirectly due to human activities (Fig. 9.14)
8.3 Introduced genetic material	Human altered or transported organisms or genes
9. Pollution	Threats from introduction of exotic and/or excess materials or energy from point and non-point sources
9.1 Household sewage and urban waste water	Water-borne sewage and non-point runoff from housing and urban areas that include nutrients, toxic chemicals and/or sediments (Fig. 9.15)
9.2 Industrial and Military Effluents	Water-borne pollutants from industrial and military sources including mining, energy production, and other resource extraction industries
9.3 Agricultural and forestry effluents	Water-borne pollutants from agricultural, silvicultural, and aquaculture systems that include nutrients, toxic chemicals and/or sediments including the effects of these pollutants on the site where they are applied
9.4 Garbage and solid waste	Rubbish and other solid materials including those that entangle wildlife
9.5 Air-borne pollutants	Atmospheric pollutants from point and non-point sources
9.6 Excess energy	Inputs of heat, sound, or light that disturb wildlife or ecosystems
10. Geological events	Threats from catastrophic geological events
10.1 Volcanoes	Volcanic events
10.2 Earthquakes/tsunamis	Earthquakes and associated events
10.3 Avalanches/landslides	Avalanches or landslides
11. Climate change and severe weather	Threats from long-term climatic changes which may be linked to global warming and other severe climatic/weather events that are outside of the natural range of variation, or potentially can wipe out a vulnerable species or habitat
11.1 Habitat shifting and alteration	Major changes in habitat composition and location (Fig. 9.16)
11.2 Droughts	Periods in which rainfall falls below the normal range of variation
11.3 Temperature extremes	Periods in which temperatures exceed or go below the normal range of variation
11.4 Storms and flooding	Extreme precipitation and/or wind events (Fig. 9.17)

Names and definition (IUCN–CMP 2012)

Fig. 9.9 Beach activities using motor vehicles strongly affect the sand structure, vegetation, vertebrates (birds and reptiles) and invertebrates (code 6.1—Recreational activities and code 7.3 Other Ecosystems Modifications; *Photo* Gianluca Poeta)

Fig. 9.10 Recreational activities (threat code: 6.1) in a sandy beach affect psammophilous vegetation (here *Ammophila littoralis* and *Anthemis maritima*) by trampling and motor-vehicle transit (Castelporziano Real Estate; central Italy). Fenced areas contribute to protect the remnant vegetation (*Photo* Corrado Battisti)

Fig. 9.11 The increase in fire frequency or intensity outside of its regime and range of natural variation represents an important factor of pressure in Mediterranean ecosystems (threat 7.1—Fire and fire suppression). Here, a fire of high magnitude completely burnt a *Quercus suber* oak (Mount Catillo nature reserve, central Italy; *Photo* Corrado Battisti and Anna Guidi)

TNC and particularly Salafsky have been given credit for constructing a standard terminology system: (i) giving a definition of project, action, threat, target, driving force; (ii) naming threats (and conservation actions; see Salafsky et al. 2008); (iii) structuring a hierarchical classification, useful as conceptual model; (iv) defining a straightforward system to quantify, compare, and put threats in order of priority, inserting the various steps of the threat-target relationship in a causal chain of events.

Recently, a debate has revolved around some aspects of nomenclature, classification, and causal relation between threats and targets. The criticism of Salafsky and colleagues' approach has been raised by Balmford et al. (2009), who have proposed a different system. These authors have pointed out that classification by categories which are embedded in a causal chain is nothing but a poor representation of real-world complexity. The system conceived by Balmford et al. (2009), similar to the IUCN–CMP system proposed by Salafsky's group, is grounded on

Fig. 9.12 Agricultural practices in land reclaimed landscapes may act changing water flow patterns from their natural range of variation (threat 7.2—Water management use). The muddy areas structured by water stress represents an opportunity for many waders (Aves Charadriiformes). Nevertheless, this anthropogenic water regime should be carefully managed because of their potential impact on freshwater communities (Macchiatonda nature reserve; Latium, central Italy; *Photo* Sergio Muratore)

Fig. 9.13 An introduced population of *Carpobrotus acinaciformis*, an alien plant species, on a Mediterranean sandy beach (code 8.1—Invasive Non-native/Alien Species; *Photo* Gianluca Poeta)

Fig. 9.14 Wild boar (*Sus scrofa*) released from hunters may increase in their density inducing structural changes in vegetation and impacting on small vertebrate communities (threat 8.2—Problematic native species; *Photo* Mario Melletti)

Fig. 9.15 Water pollution strongly affect invertebrate and vertebrate freshwater assemblages inducing demographic collapse and local extinctions (here 'Household sewage and urban waste water'; threat code 9.1, in a stream under a *Quercus cerris* oak wood) (*Photo* Corrado Battisti)

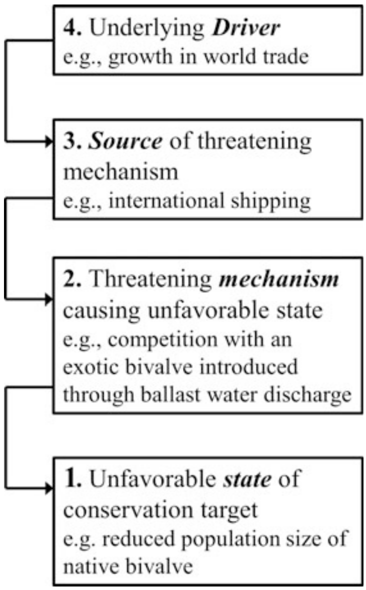
Fig. 9.16 Anthropogenic induced coastal erosion (Northern Latium, central Italy) (*Photo* Gianluca Poeta)

the definition of a causal chain “contributing factor-threat-target”. However, Balmford also introduces the concept of mechanism, keeping it separate from the concept of threat source. By contrast, in the IUCN–CMP systems, such concepts are grouped together in the same knot of the causal chain (Fig. 9.18).

Replying to Balmord’s group, Salafksy and colleagues argued that in working conditions more than distinguishing between sources and mechanisms, which can be a difficult task for the practitioners, who may lack pertaining information, it is necessary to define and evaluate the overall information connected to *direct threats*. In the IUCN system, therefore, sources and mechanisms have been intentionally grouped together due to lack of general consensus and teams may find it difficult to define a causal relationship between them. According to Salafsky and colleagues, practitioners may find IUCN–CMP system more practice-oriented and easy to use. In their opinion, the system developed by Balmford and colleagues may suffer from weak points and practical limits. In particular, with such a system (i) project teams are forced to separate threat sources and mechanisms even in uncertain and complex conditions and when information is not available; (ii) practitioners have to confront very complicated matrices; (iii) it is a non-hierarchical system; (iv) threat

Fig. 9.17 An artificial water body for horse farming, characterized by a high water level changes. These sites represent an opportunity for ephemeral and trampled water-related vegetation (Molinio-Arrhenatheretea with isolated groups of unpalatable *Juncus* sp. on the *right*). Nevertheless, in high altitude grasslands these new ecosystems may induce soil erosion and disruption of herbaceous plant associations (*Photo* Corrado Battisti)

Fig. 9.18 The four main elements of a threat causal chain (in bold) with a few examples (from Balmford et al. 2009). Threat sources (*3*) and mechanisms (*2*) which in this diagram are sequential, in the system IUCN-CMP are grouped in one element



ranking becomes a difficult task. Finally, it has been pointed out that in the catalog of mechanisms (external to the target) included in Balmford and colleagues' system, some stresses, which are internal to the target, are considered as threat processes.

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Chapter 10
Threat Regime

Homo sapiens acquisition of culture has propelled the species out of nature's ambit…(so that)… any human modification of nature is unnatural
(Callicot et al. 1999)

In analogy to what happens when treating disturbance regime, defining a range of attributes (henceforth also indicated as characteristics, criteria, or threat variables) is an important step of threat analysis as well. Such attributes allow the definition of threat regime, i.e., threat specific intensity, action modalities, and spatial articulation.

Most of the attributes of threat regime are analogous to those utilized for disturbance regimes of natural origin. However, other more specific attributes can be added, which are useful to describe event characteristics in detail and to provide precise indication as to whether an intervention is requested, about how urgent it is and which specific strategies and actions are needed.

Generally, attributes can be distinguished as (i) *basic variables*, expressing a direct evaluation of the specific event, (ii) *compound variables*, obtained from the arithmetic sums or algorithms of basic variables (for example, as explained in the following sections, *magnitude* is a regime attribute derivable from the sum of two basic variables: *scope* and *severity*).

The main attributes of threat regime are listed below.

Scope: It indicates the proportion of target which has been or is likely to be affected by a threat in the site, within a time conventionally decided by the project team (for example, the decade before or after the project), treating current conditions and circumstances as constant. For ecosystems and communities, according to their typology, scope can be measured as the proportion (frequency) of surface, volume, biomass, or coverage which has been, is, or will be affected by the event with respect to the total population. When considering entire animal or plant groups, scope can also express the absolute number (or percentage) of the targets (species, genus, families) affected by the event on the entire study area (e.g., families of birds

C. Battisti et al., *An Introduction to Disturbance Ecology*,
Environmental Science and Engineering, DOI 10.1007/978-3-319-32476-0_10

threatened by a specific event). In TNC 2000, the term ‘scope of damage’ has been introduced. It is defined as the reference geographical area where the impact caused by one threat affects one or more targets over a period of ten years, keeping constant current conditions and circumstances.

Extent: Similar to *scope*, it has a more restricted meaning (it only comprises spatial and temporal aspects). According to Ervin (2002, WWF RAPPAM Methodology), extent represents the *spatial or temporal range where activities, actions, or events occur*.

Severity: It constitutes past, present, or future pressure levels which are estimated to be caused by the threat event and may affect the target (for example, by altering its composition, structure, vitality, and integrity). Within a specified period of time (a decade, for example), it may lead to a specific alteration, degradation, fragmentation, or stress, with current conditions and circumstances being kept constant. According to TNC (2000), this term is indirectly connected to the degree of a target damage/alteration (impact), which can be expected within a decade on the basis of the above-mentioned conditions and circumstances. Such an attribute is calculated with respect to scope,[1] and for a given species it can be expressed as the degree to which the population is reduced as a consequence of a threat event.

The *severity*/*intensity* attribute can also be expressed in numerical terms, as absolute numbers or percentages, and can be calculated for each target as well as for the entire site. In the WWF RAPPAM methodology (Ervin 2002), which is specifically dedicated to an effectiveness evaluation of management in protected areas, the term “impact” is employed to mean *the degree to which a threat directly or indirectly affects the resources of a protected area.*[2] In general, intensity has been treated as having an absolute meaning, related to the pressure exerted by the threat, irrespective of the effects on the different targets (*absolute intensity*). Severity has a target-specific meaning, connected to the specific impact level exerted by a threat on one or more specific targets (*relative intensity*). In areas of conservation concern, many different attempts have been made to conduct a qualitative evaluation of severity (e.g., Kiringe and Okello 2007; Battisti et al. 2008, 2009).

As far as anthropic threats are concerned, severity is affected by a range of factors which can be either intrinsic or extrinsic to the threat (e.g., the physical, chemical eco-biological characteristics of the impacted component). It can range from low to high values, depending on various parameters (soil type, vegetation type, season, etc.). Knowledge of the factors which may affect threat severity can be useful to deal with the event.

[1]For example a fire affects 20 % of the cover of a specific plant association (*scope*: 20 % of the site; category: medium; *score*: 2; see the following sections). For this event, severity will be calculated within this 20 % value, i.e. within the action range of the threat itself.

[2]We suggest you refer also to the different meanings attributed to the terms pressure and impact within the DPSIR paradigm. The different concepts (*pressure*, *impact*, *severity*, *intensity*) are still not clearly defined and standardized.

Nature of impacts (Cole 1994): It is a descriptive attribute of the type of impact exerted by a threat on one environmental component (for example, unrestrained recreational use—IUCN category: 6.1, version 3.1—may exert the following impact: compaction and physicochemical alteration of soil, with subsequent disappearance of some herbaceous plant species). It can be used as a synonym of *mechanism* of threat (see Balmford et al. 2009).
Frequency: It indicates the number of anthropic events within the time unit. The analogous attribute of recurrence or recurrence interval can also be used.
Trend/pattern over time: It expresses the temporal trend of a threat attribute (Ervin 2002) and comprises the attributes of duration and frequency.
Timeliness: It specifies the time elapsed between the occurrence of a threat event and its effects (impact) on one or more target. In fact, environmental components can be affected by many threats acting after a time lag which varies with respect to the time of occurrence. Timeliness can be expressed with units of measurement for time (e.g., days, months, years). This attribute must not be confused with threat *duration*.
Risk or probability (also, *dangerousness*): It indicates the likelihood of a threat acting on a target (to which an intrinsic value has been ascribed) within a prefixed time interval in which the forecast can be considered valid (for example 10 years).[3] This attribute can be expressed as relative frequency (between 0 and 1) or percentage (between 0 and 100; see Ervin 2002).
Reversibility and irreversibility: It expresses the degree to which the effects of a threat can be considered reversible (or, on the contrary, irreversible). This attribute allows us to evaluate how long is needed to restore the target as well as to assess the specific modalities of the intervention. Such an attribute can be expressed on an ordinal scale by scores given by practitioners, or in a continuous way, according to the resources (financial resources, time, etc.) needed to restore the initial conditions of the target. The term *permanence* can also be used. It is the degree to which a stress caused by a stress source can be reversible. Moreover, according to TNC (2000), *reversibility is the temporal interval needed by an impacted resource to recover with or without human intervention* (*resilience time*). The attribute known as *recovery time* is considered analogous to *reversibility* and *permanence* (see Salafsky et al. 2003).
Contribute: It expresses the degree a threat is the cause of further threat events (for example, for perturbations which causes cascading events). The term is also used to mean the contribute of a threat (e.g., as a percentage), in terms of stress caused to the target, if the latter is affected by more than one threat.

[3]From a more analytical point of view, when analyzing and evaluating problems of environmental concern, risk is defined by the following product: $R = P \times \mathrm{Vu} \times \mathrm{Val}$, where P corresponds to the *probability* that a phenomenon happens in a given space with a given return period (event *potentiality to cause harm*); *Vu* is the *vulnerability*, i.e. the ability of a particular item to withstand the effects associated with the threat, *Val* corresponds to the *value* assigned to the element exposed to a danger.

Urgency: It indicates the urgency level which is necessary to counteract a threat through appropriate actions or strategies. It is also expressed as the velocity at which a threat can appear (whether it is sudden or not; Salafsky and Margoulis 1999). Such an attribute can vary depending on whether the threat is currently apparent or is likely to appear in the near future. However, some threats (e.g., non-native species invasion) can be considered to be at a very high urgency level, even though they have not become clearly evident yet. Urgency indicates the necessity of undertaking actions immediately or within a given period of time (e.g., 1, 2, 5 years).
Magnitude: In general, it represents the *capacity of a threat event to exert a pressure or an impact*. Such a composite attribute is strictly dependent on threat regime itself. In a similar manner to the other attributes, in the absence of field or experimental data, magnitude can be calculated through scores assigned by skilled practitioners. Generally (at least according to the Open Standards approach), *magnitude* is obtained by adding *scope* and *severity* scores together, i.e., utilizing the two most important and informative regime attributes.
Significance: it is analogous to magnitude and it was used by Cole (1994) to construct the wilderness threat matrix. It is obtained according to two criteria: (i) threat extent, which is a relatively objective attribute (calculated both absolutely and on a score scale) and (ii) threat importance, a more subjective parameter because, generally, it can only be obtained through expert judgment (utilizing a scored scale): it is determined by impact duration or intensity and by the rarity (or at least by their conservation value) of the impacted environmental components. Significance can be expressed by a 1–5 rating scale (Cole has suggested five levels, 1 being low, and 5 high, but the score range can vary according to the project team requirements).

Other attributes can be proposed by the project team according to necessities, targets, and threats present in a site: some can concern the evaluation of the costs of the interventions needed to counteract a given threat or the project acceptance at local community level (or, anyhow, be inherent to social aspects, as in the case of *social complexity* attribute). Some can provide indications about complex project aspects; among them: the feasibility attribute, which can be obtained by synthesizing the scores of the information connected to costs, resources, organization, environmental conditions, and circumstances (Salafsky et al. 2003).

Finally, a vast terminology related to regime attributes has been developed for the analysis of catastrophic events and natural disasters (see Alexander 2001) which may impact human populations. Such events (e.g., fires,[4] floods, geological events) are not dealt with in this book.

[4]For example, specific attributes are utilized for fires; among them: *reaction intensity*, *linear intensity*, *front height* and *length*, *propagation velocity*, *ignition* and *development probability* (Bovio and Camia 2004; Alexander 2001).

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Chapter 11
Threat Quantification and Ranking

Wilderness do not exist in a vacuum (…)
Wilderness boundaries (…) are highly permeable to pollutants, migrating animals, exotic species, noise and light, wild-fires, insects, and disease.

(Cole 1994)

In most of the sites of conservation concern (Natura 2000, protected areas), multiple threat events occur at the same time or within a given period of time. Management of such areas and conservation of certain biodiversity targets will then require an accurate analysis of extant threats, in order to sort out the most important ones, those on which intervention strategies need to be focused on. Such an aspect requires careful consideration in conservation projects, which generally suffer from resource limitation (in terms of time, available funds, manpower, equipment, and materials).

Evaluation and ranking of the threats present in a site can be carried out through the definition of some standardized procedures. They enable to quantify and subsequently compare, in a rapid and relatively simple way, the threats occurring in different sites. By such a comparison, it will be possible to sort out priority threats which deserve intervention.

A few examples of standardized procedures for threat quantification and comparison have been available for about one decade and they have been promoted by international organisms and individual researchers (e.g. Cole 1994; TNC 5-S framework: TNC 2000; WWF RAPPAM, Ervin 2002; BSP's Threat Reduction Assessment, TRA: Salafsky and Margoulis 1999; TNC's Southeastern Division Method; for a review, see Salafsky et al. 2003).

C. Battisti et al., *An Introduction to Disturbance Ecology*,
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One of the most updated approach leading to the quantification, comparison and ranking of different threats has been proposed by Conservation Measure Partnership[1] and it has also been derived by other experiences such as the WWF International's Standards of Conservation Project and Program Management.[2] In particular, this program specifically deals with threat ranking[3] within a cycle of adaptive management, aimed at determining which threats are the most important to be addressed.

More specifically, threat ranking is a procedure undertaken by a group of practitioners. It consists of evaluating and subsequently ranking all threat events acting on certain biodiversity targets, within a given period of time, in a site which is the object of management and conservation strategies. Such evaluation is performed in an 'expert' way, on the basis of judgments made by experts of specific matters (threats or environmental components) who assign scores to certain attributes or characteristics of the threats. Such expert-based approach (Linstone and Turoff 1975) is utilized in the absence of other tools and objective methodology, i.e., in conditions of urgency, uncertainty, and paucity of resources.

The definition of the criteria to be used in the evaluation process constitutes the first step of threat ranking. Generally, such criteria coincide with the attributes of threat regime. Once defined, they are systematically applied to the direct threats present in the site, through an analysis process allowing the identification of intervention priorities. Priority-based ranking is accomplished through priority ranking, according to which threat is the most important.

This relatively simple and quick method is particularly advisable when studying sites containing numerous threats and targets in certain spatial and temporal contexts. It is an appropriate procedure to employ in order to achieve a proper and objective management of protected areas. In fact, among professionals, there is a tendency to assess the relevance of a threat on the basis of a subjective analysis, limited to the immediate circumstances and focalized on events which are more easily detected (and which are defined more 'charismatic'). Actually, such events may be of minor importance in terms of the impact they exert when compared to others less perceivable events, but capable of a stronger pressure on the conservation targets (Battisti et al. 2009).

Threat ranking is also advisable because of the tendency, shared by many project teams, to develop actions aimed at mitigating threats for which intervention strategies have been already worked out, or whose regime have been already assessed. In such a way, threats which have not been appraised are likely to be overlooked, even though they might exert more marked impact on the targets.

[1]See: http://www.conservationmeasures.org/.

[2]See: http://wwf.panda.org/what_we_do/how_we_work/programme_standards/.

[3]The information reported below has been elaborated by Foundation of Success, and by WWF USA. Since the documents are constantly updated, regularly checking the site www.panda.org is also advisable.

Efforts focusing and optimization to address threats which have been ranked at high priority level, is extremely important, given the scarcity of financial resources allocated to the conservation projects. Such kind of threats can be highlighted only when they are quantified by scores (rating) and are subsequently arranged by importance (ranking).

The capacity to define a conceptual model, based on a cause–effect relationship between threats and targets, constitutes a further advantage of this kind of approach, which is useful to set conservation and management strategies.

To quantify stress and impacts, each disciplinary field has specific approaches. Over time they have developed their own rating scales based on scores assigned by professionals (e.g., in the study of natural disasters and of their effects on human populations; as far as fires are concerned, see US Department of the Interior 2003 and Kirkpatrick et al. 2006[4]).

Project team constitution is a key step in this kind of evaluation procedure. The group of expert professionals in charge of assigning the scores will have to share a thorough knowledge of: (i) components, factors, characteristics, conditions, and environmental circumstances of the site (particularly, with reference to biodiversity targets' ecology and sensitivity); (ii) anthropogenic and natural history of the site and therefore of the local threat events which have occurred in the past. Such a team will have the responsibility for assigning value judgments concerning the level of importance/impact of the threats to certain targets. Therefore, it will have to show a great deal of expertise regarding the different environmental components (air, water, soil, plants, animals, anthropogenic components). It is also important that a considerable number of professionals (not less than ten) should join the team. In this way, more data will be gathered and it will be possible to undertake a statistical analysis of the scores assigned (for example, by comparing the average scores: Battisti et al. 2008, 2009).

Threat ranking procedure is performed according to the following steps:

1. *Threat identification and assignment of a standardized nomenclature*—This first step allow us to identify the threat events which are relevant in terms of their impact on biodiversity. Such events can be present in the site when the project is carried out, have been occurred in the past or are likely to happen in the future.[5] A standardized nomenclature is assigned to such events, possibly ranking them according to various hierarchical levels (family, genus, or species of threat).

[4]These authors have developed a Burn Severity Index which allows a rapid quantification of the effects of fire on specific sampled areas. A zero score indicates no evidence of recent fires; 1 indicates low severity fires (when herbaceous vegetation is affected by fire up to the height of 0.3 m from the ground); 2 indicates intermediate fire severity: between 0.3 and 1.5 m from the ground; 3 indicates high severity fire: more than 1.5 m from the ground; 4 indicates severe crown fire. Such a visual assessment is currently used also by the US National Park Service (US Department of the Interior 2003).

[5]Human induced events or anthropic activities which have been identified in a site but do not constitute an immediate threats can be listed separately (as stated in Teofili et al. 2006: "Other activities present in the area, but not constituting a vulnerability factor for biodiversity").

Potential future threats can be included in the classification only when they are deemed likely to happen within a given period of time conventionally decided by the team.

2. *Conceptual scheme direct threat → target*—Subsequently, a scheme or conceptual model is developed which allows us to highlight the relationship between direct threats and targets (situation analysis).[6] In such a model, direct threats are associated to the ecological targets they impact, and the causal relationship is graphically represented by a line connecting the threat to its target.[7] At the end of the procedure, the threats which were formerly recorded by the team but proved not to be in direct relationship with any conservation target (and were deemed incapable of producing a stress response) will be discarded.[8]
3. *Rating and ranking*—This is the real rating step which will be treated in detail in the following paragraphs.

Rating Typologies: Absolute Versus Relative Approaches

After completing the task of threat naming and classifying, and building the relative conceptual schemes based on cause–effect relationship between threat and target, the project team will be able to evaluate the impact presumably exerted by each threat on one or more targets. Such an evaluation can be performed in an absolute or relative way.

[6]In this conceptual model, relationships of different types are obviously included: one threat to one target; one threat to more targets; more threats to one target. When only a limited number of threats (e.g. less than 5) are acting in a site, a conceptual model can be initially developed for each threat and each target separately. The threat-target relations are then ranked and only the most important will be selected. However, when dealing with numerous threats (more than 5), building up conceptual models may become a time-consuming activity. In such a case, at the beginning, ranking only the threats would be an easier task. Subsequently, a conceptual model could be developed which would be restricted only to the direct threat-target relations constituting the object of the conservation strategy.

[7]In this step a stress can be identified as the negative response of the target to the threat and measured as a variation in a given parameter or indicator. Such measure may turn out to be difficult since in most cases the target responses can be detected only when carrying out time-consuming and expensive research. Stress identification can thus be postponed to subsequent steps.

[8]The procedure can be easily accomplished utilizing Excel sheets. However, the Conservation Measure Partnership has developed a software named Miradi (www.miradi.org; 'miradi' is a Swahili word meaning 'project') which utilizes an algorithm taking into account direct threat → target ranking and makes a hierarchical ordering of such relationships in the whole site. Miradi, supported by WWF Open Standards for the Practice of Conservation, can help the team to improve a process of adaptive management. In this program, users are asked a series of questions on a step-by-step basis and this helps them define project scope, build up threat → target conceptual models, define priorities, develop objectives and actions and select indicators to evaluate strategy effectiveness.

When rating is performed in an absolute way, the project team will select one or more criteria (i.e., one or more regime attributes/variables, such as, for example, scope and severity) and define an appropriate rating scale (for example, with scores from 1 to 4); subsequently the team will assign scores on the basis of expert judgment, utilizing the chosen criteria and the rating scale pertaining to the various targets (it has been recommended that the number of threats and targets to be rated should be kept under 10).[9] This is the so called target-by-target approach and the score assigned to each threat will be connected to the impact it specifically exerts on one or more selected targets (absolute target-by-target ranking).

In a different way, in relative rating, all threats simultaneously acting on the site are considered (independently from the impact they exert on the single target), and are evaluated one with respect to the other, rather than independently. For example, if six threats are identified in a site, for a given criterion score 6 will be assigned to the threat deemed most important for the attribute under consideration (e.g. severity). The other threats will score progressively lower. As already mentioned, such approach includes assigning scores which express the overall impact apparently exerted by each threat on the entire site, without implications on the effects that the same threat may exert on specific target environmental components (relative whole-site ranking).

Each approach has negative and positive aspects. A strong point in favor of the absolute ranking is the possibility of a direct comparison of the scores assigned on specific target and threat criteria in different sites. However, since it is more analytical and informative, it implies a vast knowledge of the site, in particular of the threat effects on each target which has to be evaluated. On the contrary, a positive aspect of relative ranking, which evaluates the overall weight of the threats on the entire site, is related to the possibility that the project team can do a quick ranking of all the threat events acting in it. In this case no detailed information is needed about the impact exerted by each event on each target. In fact, relative ranking can be accomplished also when information about threat regime and threat–target relationships is limited or insufficient. However, a weak point of this method is the impossibility of a comparison among the scores obtained for threats acting in different sites, due to the classification system itself. In fact, it entails the assignment of a specific score which become significant only if it is related to the specific site context since it is dependent on the overall number of threats (i.e., on the number of assigned ranks).

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[9]When dealing with threat quantification, practitioners are confronted with the task of deciding whether threats need to be rated according to a continuous scale (e.g. *scope* rating as a percentage ranging from 0 to 100) or by categories (*scope* rating by categories: 0–25 %; >25–50 %, etc.). Generally, continuous measures are more precise but difficult to be obtained, unless appropriate tools and analytical methods are available, at least for certain regime attributes. For the most part, a gross estimate conducted on a category basis can provide enough information in conservation projects including a threat analysis. Given the non-linear nature of many ecological processes, it might be appropriate to subdivide the total range (e.g. 0–100 %) into classes of unequal dimensions chosen by the project team according to necessities (for example, 0–5 %; >5–25 %, etc.).

It should be remembered that the scores obtained for the individual target may differ from those calculated for the entire site. In fact, threats which score high when assessed for the site can score lower when individual targets are considered. Therefore, a fundamental step before assigning the scores is choosing between a site-based strategy (centered around the most important threats acting on the overall site, irrespective of their effects on specific targets: relative approach) and a target-based one (centered around specific targets and the relative threats: absolute approach).

Relative approach may prove more useful when the ordinary management of a site is conducted by territorial Agencies (in Italy for example, Regions, Provinces, and park administration Agencies), whereas for specific conservation projects or for defining measures in management plans dedicated to the Special Areas of Conservation (SAC) and to the Special Protected Areas (SPA), a target-based absolute approach is more advisable. In fact, in such cases, the main targets are constituted by action plans devised for species or habitat types.

Arithmetic Versus Comparative Approaches

For an overall evaluation of threats, two different kind of approaches can be followed: the arithmetic approach and the comparative one.

Arithmetic approach is based on the arithmetic sum of the scores obtained by the individual attributes or criteria utilized for the analysis (e.g. scope + severity + ⋯). It allows us (i) to obtain a preliminary quantification of the overall magnitude of the threat event acting on the site targets (or on the entire site irrespective of the individual targets); (ii) to compare the different threat events among them (ranking them according to a descending order of impacts).

As already mentioned, score assignment should be carried out by a group of experts, endowed with professional skills and a thorough knowledge of the history, targets and anthropogenic components of the study area. Each expert should then go on with rating, by assigning score on a defined scale. In order to achieve a shared score, the different ratings could be compared or, alternatively, individual scores could be assigned independently by each expert (Delphi Method, 'open' and 'closed', Linstone and Turoff 1975).[10] Mean values and medians could be obtained adding the individual scores produced independently by the various experts ('closed' Delphi method). Such values would be useful in the case the scores given to the threat regime attributes were subjected to a statistical comparison (e.g., in the same site, before and after a conservation project; among different sites; among

[10]Experts can assign scores both in an independent secret way (averaged values will be considered, 'closed' Delphi) and jointly, following a shared agreement (a single score which the whole team agrees upon for each attribute, 'open' Delphi). Each approach has different kinds of implications (for example, in the open Delphi averaged values cannot be obtained; moreover, results may be biased by the presence of leader personalities).

groups of experts differing for social classes, culture, age, etc., compare Battisti et al. 2008, 2009; Carboni et al. 2010).[11]

In this approach each attribute has the same weight. Alternatively, different weights could be attached to the various threat attributes, multiplying them by a constant.[12]

Differently from the arithmetic procedure, in comparative procedures, a simple double entry matrix could be built. This could lead to an easy attribution of threat magnitude, calculated in a comparative way, by considering the scores obtained from the two major regime attributes (e.g., scope/extent and severity). For example, a threat with high scope and intermediate severity would gain an intermediate magnitude score. Such a procedure allows us to compare the threats present in the same site (TNC 2007).

A more thorough discussion of arithmetic and comparative procedures (absolute and relative) will be presented in the following paragraphs.

Absolute approach based rating (arithmetic procedure). According to this kind of approach, rating is constituted by a two-step procedure.
Criteria identification. Criteria identification for threat ratings, i.e., identification of the regime attributes (or variables) to which scores can be assigned, is the first step of this kind of approach. Threat regime is characterized by different attributes and each of them allows us to gather information about specific aspects of the events.

From a theoretical point of view, all attributes can be subjected to rating. However, assigning scores to some of them may result difficult, especially when information about their characteristics is totally lacking or insufficient. Assigning scores to a high number of attributes may also be extremely demanding for the team and scarcely informative. Moreover, it may increase bias due to subjectivity, lack of knowledge and mistaken evaluation of phenomena characterized by a high level of uncertainty. Thus, generally, it has been suggested that the number of criteria should not exceed 4. According to the procedure proposed by Open Standards (see also WWF 2012),[13] the most representative criteria, those which allow us to gain information about the weight (or impact level) of a threat on a target, are *scope*, *severity*, and *irreversibility*.

Threat ranking application: After threat–target scheme has been designed (see previous paragraph), the team will assign a score to each threat. The score will be

[11]Ranking can also enable statistical correlations among sets of threats in different sites and times (for example by a simple non-parametric linear correlation test as the Spearman rank test). It can be verified whether threat magnitude (or single attributes such as scope, severity, etc.) in a site can be correlated to that in another site, or in different times (e.g. before and after the fulfillment of certain projects, or the occurrence of certain events).

[12]For example, should the weight of extent/scope attribute be considered more important than that of severity, irrespective of their values, the score assigned to extent could be multiplied by 2 and the score assigned to severity by 1. However, when assigning such coefficients, a cautionary rule should be followed, in particular when the event is not well known and uncertainty is high.

[13]Date of the last web update.

related to the modalities of the impact exerted on each target according to prior criteria. The following scale will be used after choosing score, severity and irreversibility as criteria to be considered. (It should be pointed out, however, that other criteria and scales might be chosen as a function of different targets, times, contexts, conditions and circumstances).

– *Scope*:

  score 1 (low). The direct threat affects a small proportion (e.g. 10 %) of the surface/volume/cover/biomass of the ecosystem/community/population;
  score 2 (medium). The direct threat affects a significant proportion (e.g. 11–30 %) of the surface/volume/cover/biomass of the ecosystem/community/population;
  score 3 (high). The direct threat affects a huge/ample proportion (e.g. 31–70 %) of the surface/volume/cover/biomass of the ecosystem/community/population;
  score 4 (very high). The direct threat affects a high proportion, if not the total, (e.g. 71–100 %) of the surface/volume/cover/biomass of the ecosystem/community/population.

– *Severity*:

  score 1 (low). For a given scope the direct threat affects the target superficially (e.g. within the following decade or the next three generations, population decrease is expected to range between 1 and 10 %);
  score 2 (medium). For a given scope the direct threat affects the target moderately (e.g. within the following decade or the next three generations, population decrease is expected to range between 11 and 30 %);
  score 3 (high). For a given scope the direct threat affects the target seriously (e.g. within the following decade or the next three generations, population decrease is expected to range between 31 and 70 %);
  score 4 (very high). For a given scope the direct threat affects the target in a very serious way (e.g. within the following decade or the next three generations, population decrease is expected to range between 71 and 100 %).

– *Irreversibility*:

  score 1 (low). Direct threats effects are reversible and the target can be easily restored keeping costs relatively low and/or within short periods of time (e.g. 0–5 years);
  score 2 (medium). Direct threats effects are reversible and the target can be easily restored at reasonable costs and/or within ampler periods of time (e.g. 6–20 years);
  score 3 (high). In this case, target restoring is theoretically feasible, but only at high costs and within relatively long periods of time (e.g. 20–100 years);

score 4 (very high). In such a case, direct threat effects may not be reversible, target restoring may result difficult or only at very high costs and/or within very long periods of time (e.g. 100 years).

As already mentioned, the most important ranking criteria are constituted by *scope* and *severity*. The preliminary information provided by these two attributes taken together, provides a reliable indication of the overall impact level of the threat (aka magnitude). Therefore, when assigning scores, the result obtained by the sum of their values is multiplied by two indicating that they are more important than irreversibility. For each threat and target, magnitude score can thus be obtained from the following simple equation:

$$\text{magnitude} = 2 \times (\text{scope} + \text{severity}) + \text{irreversibility}.$$

Likewise, through such an equation, assigning a score to direct threats is equally simple and allows us to rank them according to a descending order of importance for the entire site under study. This can be obtained by merely adding the scores (of each rated criterion or of the overall magnitude) obtained for each threat from all the targets. Team efforts will be centered on the threats which have obtained the highest scores.

Score evaluation is a subjectivity-prone task, even when performed by professional teams; so, the differences among numerical values may not reflect a real difference in the magnitude values assigned to the threats, as rating and ranking are imprecise, subjective processes, resulting from an expert-based procedure. Therefore, grouping scores according to magnitude categories ('very high', 'high', 'medium', 'low'), each defined by its range of minimum and maximum values, is a more appropriate procedure. Magnitude categories are more suitable to define project priorities than the numeric scores. Attention-requiring categories need to be previously defined by the team ('very high' or 'high', etc.).

Relative-approach based rating (arithmetic procedure): The method adopted by Margoluis and Salafsky (1998) consists in evaluating all the directs threats detected in a site (on the basis of some previously defined criteria). This allows both a comparison among sites within the same time interval, and among situations recorded in different times for the same site, without considering the impact on the individual targets. The scores are calculated, in a relative way, as total values on the entire site (in the WWF Standards, scores were calculated in an absolute, target-by-target way).

These authors utilize the following attribute regimes, scope, severity and urgency, as criteria. In contrast to the WWF Standards, in the overall rating of threats for each site (which, therefore, is not absolute and target-specific), irreversibility cannot be used as a criterion, since it is strictly connected to the target (in fact, it can be considered a resilience indicator of each target). In this case, such a criterion cannot be applied, because the goal is an evaluation of the overall impact of the threat on the entire site (i.e., on all the targets present in the site, irrespective of their specificity, and, therefore, resilience).

To obtain a relative ranking, a multistep procedure is indicated as follows:

- *Listing all the threats detected in a site* (named and classified according to IUCN-CMP 2012). A matrix can be created utilizing an Excel sheet: threats are placed in the rows and criteria (e.g. scope, severity, urgency) in the columns.
- *Rank assigning*. Each threat will be ordered according to a progressively descending position depending on the proportion (*scope*, calculated as surface, volume, biomass, etc.) occupied in the site. The highest value (highest rank, corresponding to the total number of threats) will be assigned to the perturbations which are considered to prevail (for example, if six threats are known to act in a sites, the threat with the highest *scope* will be ranked 6). Similarly, for each threat a rank will also be assigned for *severity* and *urgency*;
- *Sum of the ranks*. It is aimed at obtaining a total value for magnitude, according to the simple equation:

$$\text{magnitude} = 2 \times (\text{scope} + \text{severity}) + \text{urgency}.$$

- *Classification of threats in categories* ('very high', 'high', 'medium', 'low'). To assign the obtained values (ranks) to categories, the total range can be divided by the class number (for example 4). In such a way, each class will be assigned its own range. The values resulting for the individual threats will be compared to the category ranges. This will enable the assignment of each threat to a specified category which corresponds to its level of importance (very high, high, etc.). The team, though, can adopt other conventions according to necessities. Other regime attributes can also be chosen as rating criteria by the team.

Comparative procedures. A comparative procedure has been proposed by The Nature Conservancy (TNC) as a part of the Conservation Action Planning Tool (TNC 2003[14]). Also in this case, quantification is carried out first by the definition of criteria, i.e., the regime attributes to be scored and rated. The choice depends on the available time and is related to the team's expertise level. *Scope*, *severity*, and *reversibility* are proposed, and, for each criterion, rating categories are directly assigned ('very high', 'high', 'medium', and 'low'). TNC has provided a detailed description of the method requested to combine results (Salzer 2007). In particular, at first, for each relationship threat-target, two values can be obtained for the most important attributes, *scope* and *severity*. Then, they will be compared in a matrix, in order to obtain a *magnitude* score. Alternatively, other matrices can be created to compare other attributes (e.g., *severity* vs. *irreversibility*).

[14]For further information, we refer you to the content-rich TNC web sites: for example, www.conserveonline.org and www.nature.org.

Once magnitude categories have been calculated, in order to assess the overall impact of the threats acting on one target, many targets or on the entire sites, final scores can also be calculated following some conventional procedures.

The first is called ‘2-prime rule.’ This rule states that if the ‘very high’ category includes at least two scores (or if there are at least 3 threats in the ‘high’ category), the total score will be ‘very high’; if in the ‘high’ category there are at least the equivalent of two scores, the global rating will be ‘high’.

The second is called ‘majority rank override’ rule. If the target majority (more than 50 %) is affected by threats which have been rated ‘very high’, ‘high’, or ‘medium’, then threat status in the site will be, respectively, ‘very high’, ‘high’, or ‘medium’.

The application of one of the previous rules will lead to an *overall threat rank* for the site. A threshold category, beyond which the threats become the object of management procedures, will be identified by the team (e.g. all the threats starting from those belonging to the ‘medium’ category).

Influence and Knowledge Analysis

A similar approach has been developed by Cole (1994) for the USA Agriculture Department. This author has devised a synthetic method which allows us to evaluate threat impact on different environmental components also when their regime is only scarcely or incompletely known, and their cause–effect relationships are poorly understood. It is thus possible to create a matrix (wilderness threat matrix) in which potential and real threats to a site (columns) and the environmental components are displayed (Fig. 11.1).

A matrix can be created for a prompt evaluation of two aspects (each characterized by its own matrix): (i) the presumed impact exerted by the threat on the target (*influence* or *significance* analysis), (ii) the practitioners’ knowledge degree of the causal relationship threat-target (*knowledge* analysis).

In each cell of the significance analysis matrix, the entries are constituted by scores (significance rating) corresponding to the extent of the threat impact on each target (significance can be considered synonymous with magnitude). To this end, Cole (1994) has suggested a scale ranging from 1 (low significance) to 5 (high significance). Once score assignment has been completed, mean values can be calculated (mean significance rating) among all threats for each component, and among all components for each threat.[15]

[15]This allows us to perform further statistical analysis aimed at verifying the significance of the differences in mean (and median) values and among threats and components (using non parametric approaches like the Kruskal–Wallis or Friedman Tests).

		Recreational activities	Grazing	Attività minerarie	Fires	Alien species	Water stress	Water pollution
Natural and cultural components	Air	1	1	1	2	1	1	4
	Freshwater communities	4	3	3	4	4	3	4
	Rocky habitats	1	2	2	1	1	2	1
	Soil	3	3	2	5	2	2	4
	Vegetation	3	3	2	5	4	3	4
	Invertebrates assemblages	4	2	2	4	3	2	2
	Landscape	2	3	2	5	3	2	4
	Cultural resources	3	2	2	2	1	1	1

Fig. 11.1 Example of a 'threats (*columns*)/environmental components (*rows*)' matrix (wilderness threat matrix). In each intersection cell, the entry is constituted by the impact (as score, category or some other modalities) which every potential activity or direct threats presumably exerts on various environmental components (from Cole 1994). The interactions among threats or components are not shown. In this example the standardized IUCN-CMP nomenclature was not utilized

A similar matrix can also be constructed in knowledge analysis. Its entries will be constituted by the assigned scores (*knowledge rating*) expressing team's expertise levels about each relation threat-target. The author has suggested that scores range from 1 (null or limited knowledge) to 5 (much knowledge). Knowledge rating must include information about (i) impact nature; (ii) cause–effect relationship between threat and target; (iii) impact extent and severity. It will be a team concern, through a process of self-evaluation, to assess how much these aspects are known. Also in this case, it will be possible to calculate the mean knowledge rating by considering all threats for each component or all components for each threat.

Finally, a comparison between *significance* and *knowledge* values will be useful to gain an understanding of how much research is still needed to gather reliable information about threat nature and impact type and the cause-and-effect relationships between threats and natural components.

Significance and knowledge values can be plotted in diagrams, one for each threat, where each point represents a specific environmental component. The points below the diagonal refer to the environmental components, which, for the specific threat, need to be further investigated (in terms of threat nature and the impact they exert and of the cause-and-effect relationships between threats and targets). To this end, a simple method to identify priority items, which research projects need to be focused on, has been suggested by Cole (1994). In particular the following criterion can be applied in relation to each threat diagram:

– if significance ≥ 3 and knowledge ≤ significance, the relation component-threat is most in need of further research (rating 5, high);

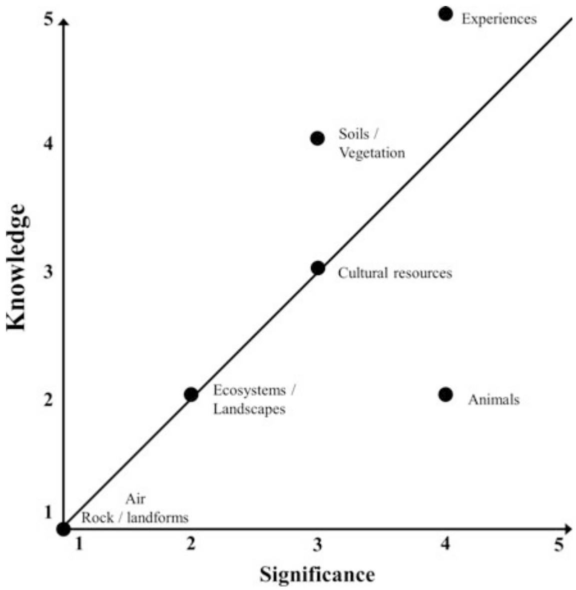

Fig. 11.2 Graphic representation plotting significance of impacts and knowledge about the impacts of a specific threat on different natural components. Environmental components (aka wilderness attributes) placed under the diagonal (representing the points of equal significance and knowledge ratings) are the ones most in need of further research efforts (from Cole 1994)

– if significance ≥ 3 and knowledge ≥ significance, the relation component-threat is a moderate priority research item (rating 3, moderate);
– if significance ≤ 2, regardless of the knowledge value, the relation component-threat is a low priority research item (rating 1, low) (Fig. 11.2).

Low (L), moderate (M) and high (H) priority categories will be applicable to each component-threat relation; therefore, it will be possible to place them in the matrix cells.

L, M and H categories may be substituted, in the matrix, by ratings 1, 3, and 5. The mean values for each row and column will constitute, respectively, the Research Gap Index values for each environmental component (mean value calculated among all threats), and for each threat (mean value among all environmental components). In each cell, a value can be placed (on a given scale, e.g. from 1 to 5), which expresses the impact of the specific threat on each component (*significance* analysis). In a similar way, in *knowledge* analysis, each cell can display the level of knowledge about the specific threat-component relationship.

Environmental Impact Assessment (EIA)

The aim of the EIA is to evaluate and quantify the expected effects of a designated activity performed in a given site. Such effects vary over time and their evaluation must concern every predictable step, including worksite activities and those carried out in the operating phase. It is important to evaluate the effects exerted by such an activity on the environmental components, considering different scenarios and how it would be in the absence of the project (zero option).

EIA is a political-administrative procedure based on an articulated series of technical–scientific documents and research which, taken together, constitute the Environmental Impact Study (EIS). A list of EIS contents is given below:

(i) a description of the activity to be carried out in a site (its physical characteristics, the description of the started projects, the materials employed or produced, the type and quality of emissions and residuals resulting both from the project and the designated activity). From a threat analysis viewpoint and drawing upon DPSIR terminology, the *activity* can be considered as the *pressure source* (or *threat factor*) potentially capable of starting mechanisms and impacts in such a way that the status of the ecological targets of a site can be affected;
(ii) a description of the alternatives addressed by the commissioner justified on the basis of their different environmental impacts;
(iii) a description of the environmental components that might be affected by the activity (water, air, soil, climate, fauna, flora/vegetation, human population, historical, archeological architectural, ecosystem services and their integration);
(iv) a description of the likely effects exerted on the targets (positive and negative impacts) mainly due to: (a) the presence of the activity; (b) the use of natural resources; (c) the emission of substances external to the site. Methods, measurement modalities, and indicators need to be specified. Impacts must be distinguished for the various stages, including worksite activities.
(v) a description of the measures employed to decrease or compensate for the negative impacts.

To gain an estimate of the impacts, a range of specific models are employed. They differ on the basis of the assessments involved, as indicated below.

A model can investigate (i) the perturbations produced in a site (e.g. *interference generation models*); (ii) the propagation modalities of such perturbations in the environment; (iii) the initial conditions (*state models*) or the conditions related to a given instant following the perturbation (*degradation models*); (iv) the impact exerted (and the produced effects or responses) on certain sensitive ecological targets (*sensitivity models*); (v) the subtraction of ecological value induced by the activity (*value models*); (vi) the prevision and evaluation of the impact (*information flow models*). As far as the latter models are concerned, a range of different approaches can be employed (*coaxial matrices*, *networks*, *thematic map overlay*). The coaxial matrices are correspondence tables enabling the representation of the relations among variables. For example, in the EIA, the Leopold matrix is a double entry matrix in which the project actions (rows) correspond to the environmental characteristics, components or variables of interest (columns).

A synthetic evaluation can be conducted using Chernoff icon plots which are associated with synthetic value judgments (positive, neutral, negative effect). Such icons can be easily understood also by a lay audience.

Matrices, because of their rigidity, cannot be employed to schematize complex cause–effect relationships. To this end, *block diagram networks* can be used in which all the items of a pressure impact process on certain targets can be sequentially ordered. These are analogous to the threat analysis causal chains. Components and indicators (of pressure, state, impact; compare DPSIR model) can be associated to the network blocks.

Finally, through thematic map overlay, the environmental values of the context under study will be compared to the activities and their impacts. In such a way, the following maps can be obtained (see Malcevschi 1998):

- vulnerability maps, gathering thematic information related to specific vulnerability factors (due to pressure level, target sensitivity and exposition);
- maps of expected perturbations and impacts derived from the planned activity. These are descriptive maps which allow us to gain information about the most likely impacts (*critical areas*: such areas correspond to the contexts where the highest vulnerability levels, in terms of target value, their sensitivity and exposure to the pressure, coexist with the highest perturbation levels).

In the threat analysis approach, scores can be assigned to the various regime attributes for each type of perturbation.

EIA is a huge and ever-changing disciplinary field: therefore for further readings, we refer you to the articles available on the specific subject (Bettini et al. 2000).

In a similar way, matrices, maps, models, and indicators can also be employed in the evaluation processes for Strategic Environmental Assessment (SEA). In such a case, matrices are created to characterize the effects produced by a plan/program on a medium/large scale (Provinces, Regions).

Further Tools for Threat Assessment

The DPSIR model: To implement a conservation project, the definition of strategies, programs, goals, and actions is the accomplishment of a project team. To such an end, the development of a framework—i.e., a synthetic model of the system which the project is going to affect—is a useful technique to highlight the relations among the different project stages (e.g., among the actions performed and the outcomes achieved). Such a framework, called DSPIR (acronym for Driver, Pressure, State, Impact, Response) enables us to unravel the hypothesized or actual causal chains linking driving forces, threats, and conservation targets. DPSIR was developed by the European Environmental Agency (EEA 1995; Kristensen 2004) to expand a previous model called PSR (Pressure, State, Response).[16]

It is used to correlate, according to a logical framework, various information concerning the state and the modifications occurring in a given environmental context. The definition of a set of indicators for each step of the causal chain will enable the monitoring of every item of the model. In this way, for any set of events constituting the strategy objective, it will be possible to define appropriate indicators of the driving forces, the pressure exerted by the threat event, the state or condition of the affected targets, the impact acting on the target, and the responses given by the project team in terms of management strategy and conservation. Essentially, DPSIR framework allows us to synthesize the information concerning the relationships between society and environment and it can be useful to develop a monitoring and adaptive management strategy. It can be considered a complementary approach to threat analysis.

In the DPSIR framework, the *driving forces* are constituted by the many activities, social, economical, and cultural factors which exert a pressure on the environmental components and systems; *pressures* are the many continuous or discrete human actions causing modifications of the original *state* of the natural systems[17]; *state* represents the combination of the conditions of a given target environmental component with the physical, chemical, and biological factors of a system in a given instant or time period; *impact* is a modification occurring in the system or in its components following the threat event (i.e., following the pressure exerted by the threat); a *response* is constituted by all the actions performed to limit or suppress the pressures and the negative effects/impacts and to maximize the positive effect/impacts (Aldrich et al. 1995; Kristensen 2004). Responses can be performed at all levels of the DPSIR framework (Fig. 11.3).

Generally, main factors and *driving* processes can be pointed out which lie at the basis of many of the current pressures (in DPSIR, *pressure* is considered as a synonym of *threat*). They are: (i) the economic aspects (specific economic activities); (ii) social and cultural processes; (iii) recreational and touristic processes/factors; (iv) factors and processes generally connected to the anthopization of the territory in the broad sense (e.g., high demographic density). More specifically, in the economical and social context, specific categories of driving forces can be identified. They can be subdivided into the following sectors: agriculture, energy, industry, transport, urbanization/infrastructure, communication, population in the broad sense, tourism, commerce, recreational activities. A full range of activities and anthropogenic disturbances can be included into such general categories; these act

[16]In a conceptual framework an attempt is made to interpret and describe reality through a symbolic language which is understandable by human logic, also resorting to the schematic and abstract description of the complex systems characterizing the 'real world'. It can be used as a tool to make previsions about future phenomena, on the basis of the current data and information held by the research group.

[17]According to the DPSIR model, pressures can be subdivided into three large categories: excessive use of natural resources, change in soil usage and cover, emissions (of waste material, radiations, and chemical compounds) into air, water, and soil.

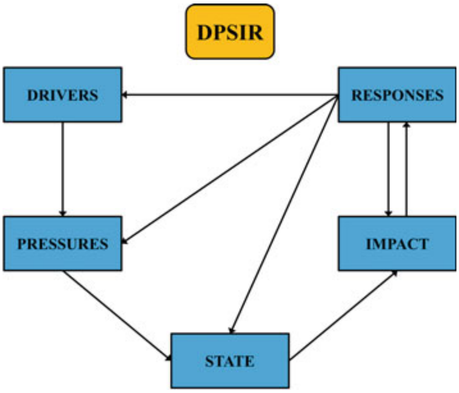

Fig. 11.3 DPSIR framework of European Environment Agency (Kristensen 2004). *Arrows* indicates the actions of each model component (from Piemonte ARPA 2008)

on large areas, as in the case of the territory physical consumption (with subsequent fragmentation) and the transformations at a landscape scale (forestation/deforestation, agriculture, cattle breeding and grazing, aquaculture, linear infrastructure, pollution, introduction of alien species, waste accumulations, fires, mining, overexploitation of biological resources and many others; Lande 1998; Theobald 2003; Lindenmayer and Fisher 2006).

Pressures cause *impacts* on the environmental components.[18] Impact is therefore the consequence of an action, event, mechanism, factor, or process acting on a given environmental target and leading to a change in its *state*. Such a change may have environmental consequences in the strict sense, but also entail economic, social, cultural and sanitary implications.

Generally, every action or human activity causes an impact on certain environmental components (individuals, populations, species, communities, ecosystems, and processes) at different scales. Therefore, defining the level beyond which an impact, for its effects on the target components relevant to conservation, must be considered within a strategy, is an important step.

The impact may be followed by a stress acting on the environmental component affected by the perturbation. The term *impact* has fully entered into the lexicon of applied environmental disciplines, particularly it is used in the *Environmental Impact Studies* (EIS) leading to the technical, political, administrative procedure called *Environmental Impact Assessment* (EIA).[19] In the applied disciplines, the

[18]In many sectors of the conservation disciplines, the distinction between pressure and impact is not definite and still far from being clarified. For example, in the disturbance–response analysis, Martorell and Peters (2009) define pressure as how much chronic disturbance is experienced by a species. However, according to the definitions reported in our book, the meaning is more similar, if not coincident, to that of *impact*.

[19]EIA is concluded by the final judgment expressed by the practitioner about the effects exerted on the environmental components by one or many perturbations occurring as a consequence of an activity/project, in order to mitigate or compensate for them. For further information, we refer you to the ample literature on the subject in which a specific terminology can also be found.

term *impact* is associated with the alteration of a specific component or entire systems caused by interventions of external origins (in this case the planned activities). Similarly, the term impact is also employed in the *Strategic Environmental Assessment* (SEA), which is aimed at assessing the compatibility of the orientations expressed in plans and programs with the environmental components located on the relatively large areas on which such plans and programs will exert their action. In SEA, all significant impacts are taken into consideration: secondary, cumulative and/or synergistic; those occurring in the short, medium and long term; current and temporary; positive and negative.

The DPSIR model is used within EIA and SEA. According to such framework, the actions performed to counteract a disturbance can also be performed upstream on the driving forces or downstream, e.g., modifying the impacts and thus lessening threat effects. In such a way, strategy identification becomes easier with net gain of time and economic resources.

The DPSIR model operating procedures are easy to perform and straightforward since the model allows us to identify and accurately characterize every component factor and relation. Therefore, it is helpful to identify effective strategies, actions and monitoring indicators, the latter process being considered the periodic assessment of the conservation project effectiveness.

As far as the indicators are concerned, in the DPSIR model, information related to the environmental issues is acquired through specific categories which are listed as follows[20]:

- *driving force indicators*: they identify the causal factors of the pressures which are capable of inducing changes within the environmental systems. They are expressed by indexes and metrics used to quantify the economic activities (for example, agriculture, tourism, etc.) or the territorial processes connected to the human presence (for example, human density).
- *pressure indicators*: they identify the variables which are potentially or effectively capable of producing environmental alterations in the broad sense.
- *state indicators*: they are descriptive indicators and define the conditions in which the target component is found. They are useful to evaluate the degree of environmental alteration and to compare the component conditions before and after the anthropogenic events, also using indexes of *state variation*;
- *impact indicators*: they are utilized to characterize the cause-and-effect relations among pressures, state and impacts; they are calculated on the impacted environmental component;

[20]In 2003, ANPA (Italian National Agency for the Protection of the Environment), AAA (Italian Association of Environmental Analysts), and SITE (Italian Society of Landscape Ecology) created a working team on the subject ‘Ecosystem indicators for territorial Agency.’ The team’s goal was to build up a data base of environmental indicators which were initially subdivided according to: *fields of applications*, *spatial level of definition*, *positions along the DPSIR causal chain* (further examples in ANPA 2000). Since these are all working projects, for any update we refer you to the project coordinators (S. Malcevschi, Italian Association of Environmental Analysts and ISPRA, Italy).

– *response indicators*: they synthetically express the efforts made by management and conservation practitioners (politicians, decision makers, technicians, planners) to deal with anthropogenic pressures.

In a similar manner to the DPSIR model, causal chains are also used in other frameworks. Besides those which are going to be reviewed in other sections of the book, it is worth mentioning the GIWA (Global International Waters Assessment) analysis applied to aquatic ecosystems (Kristensen 2004; see http://www.eea.eu.int/ and the website of the Danish National Environmental Research).

SWOT analysis: Together with the DPSIR approach, which facilitates the definition of causal relations among events, identifying participants and indicators for every process stage, a SWOT analysis is another useful tool. It can be utilized when a desired state needs to be achieved through goals and actions within a given strategy. SWOT is an acronym for Strength—Weaknesses—Opportunities—Threats. It is based on the assumption that, conditioning internal factors (points of strength and weakness) and conditioning external factors (opportunities and threats) can be found in a given project. The external factors can be of technological, macroeconomic, normative, and sociocultural types. Therefore, in SWOT analysis, threats are considered as conditioning external factors which are capable of interfering with a strategy or project.

When defining a conservation/management strategy, the team has to make decisions and to identify precise goals. In doing so, it has also to determine which are the specific goals to be achieved and to verify their feasibility; should the objectives turn out to be unattainable, they will be eventually modified. A SWOT analysis can be helpful to define strategies because it forces the project team to answer several questions about the case study. For example: (i) how can we use every internal point of strength? (ii) how can we eliminate/reduce the internal weaknesses? (iii) how can we explore/utilize every external opportunity? (iv) how can we reduce/eliminate the external threats?

In a SWOT analysis, matrices are built to contain lists of internal and external conditioning factors (Fig. 11.4 for an example). Such matrices can be purely descriptive, even though the assignment of different scores to the conditioning factors can also be considered. In such a way, a priority order for each factor is defined. After having defined the factors, it is necessary (i) to verify whether it is possible to match the points of strength to the opportunities (matching phase); (ii) to identify possible strategies useful to turn threats into opportunities and points of weakness into points of strength (converting phase). An attempt will be made to reduce or eliminate all threats (external conditioning factors) and weaknesses (internal conditioning factors) which cannot be converted.

When doing a SWOT analysis it is important (i) to be *realistic* when listing the various points; (ii) to have a *thorough knowledge of the current conditions* and to know exactly what to expect from the desired situation, (iii) to limit the number of factors (it is advisable not to exceed 8–10 factors per category or even less), (iv) to

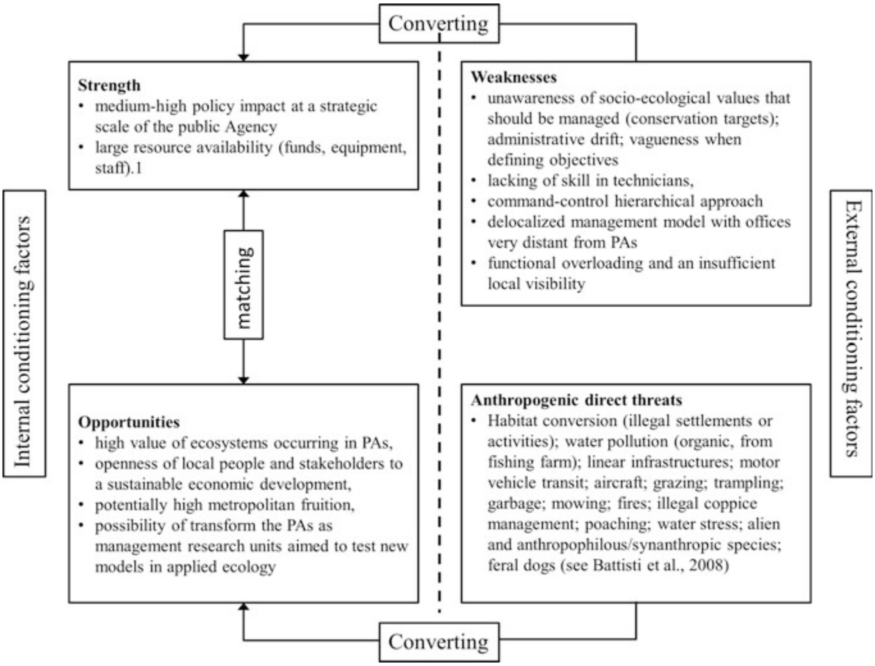

Fig. 11.4 Conceptual framework of internal and external condition factors (SWOT analysis) related to the system of protected areas (PAs) in Province of Rome (central Italy), managed by the Province of Rome—Environmental Service (PRES; from Battisti et al. 2013)

remember that the analysis is biased (subject to the team's personal attitudes); therefore it is advisable to engage an adequate number of experts equipped with a wide knowledge of the territorial issues at stake.

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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

[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).

C. Battisti et al., *An Introduction to Disturbance Ecology*,
Environmental Science and Engineering, DOI 10.1007/978-3-319-32476-0_12

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.

[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).

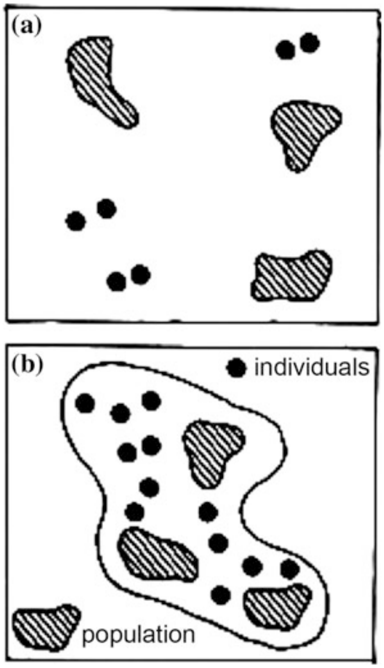

Fig. 12.1 **a** Example of distribution map of some species' individuals (indicated by *symbols*) and populations (indicated by a *cartographic unit*); **b** Example of a species distribution map, which includes individuals and populations (from Cristea et al. 2015)

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

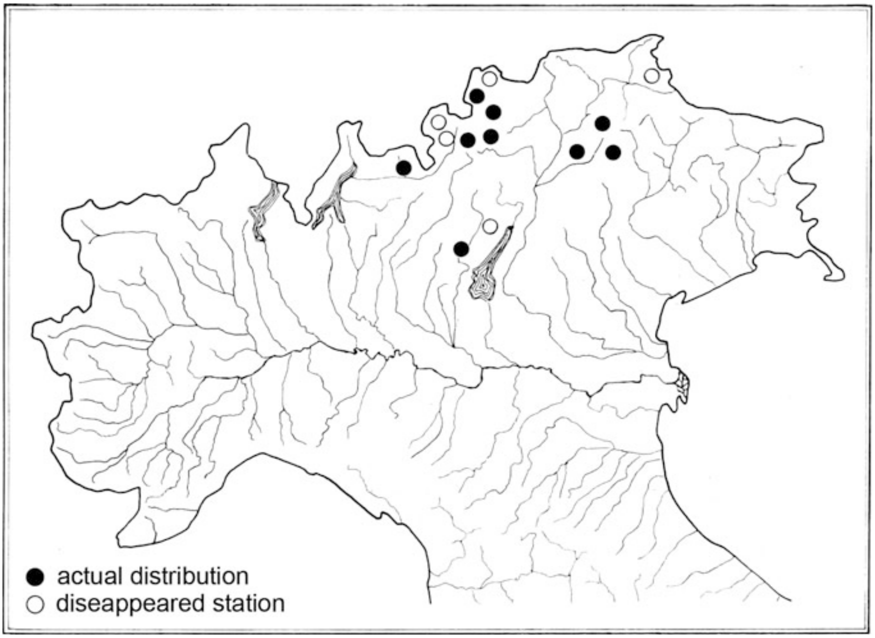

Fig. 12.2 Italian distribution of *Paludella squarrosa* (Hedw.) Briq. (from Cortini Pedrotti 1979, modified)

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,

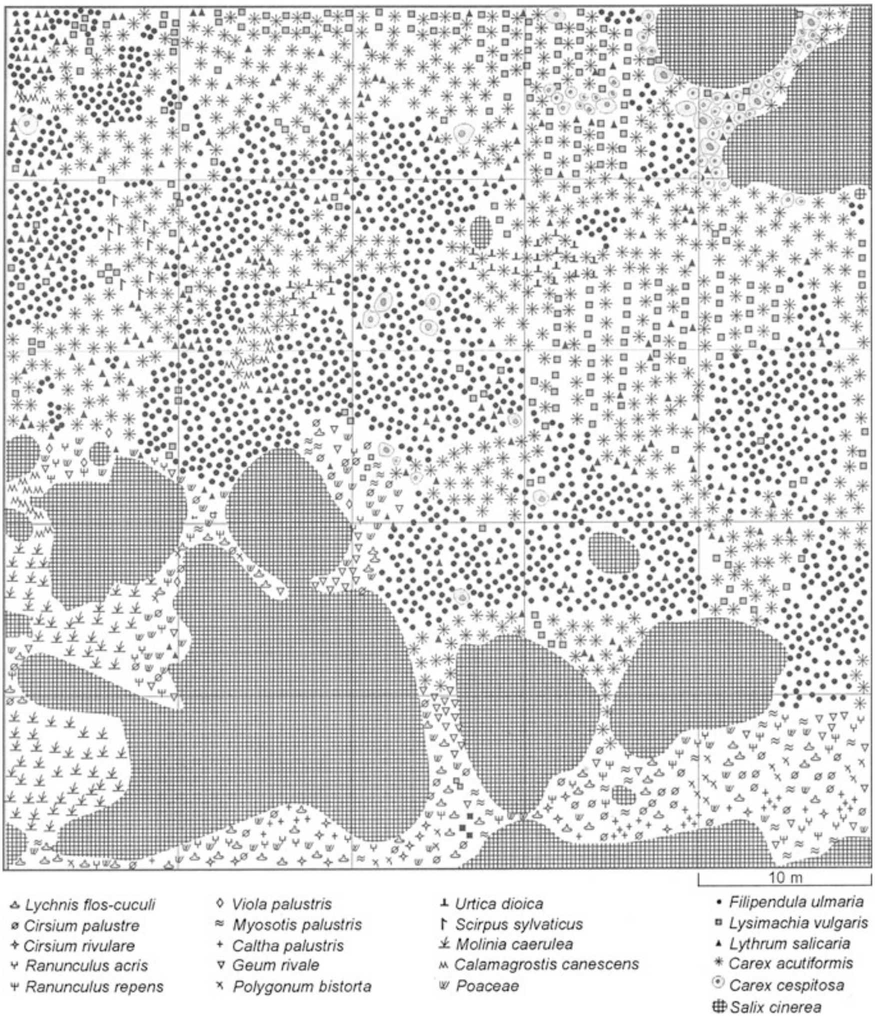

Fig. 12.3 Map of the phytoindividuals of 25 perennial herbaceous species in a meadow area of 50 × 50 m at Remski, Bialowieza, Poland. Each symbol is related to a single phytoindividual; the phytoindividuals of *Salix cinerea*, a shrub species, have been mapped with a continuous surface (from Falińska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

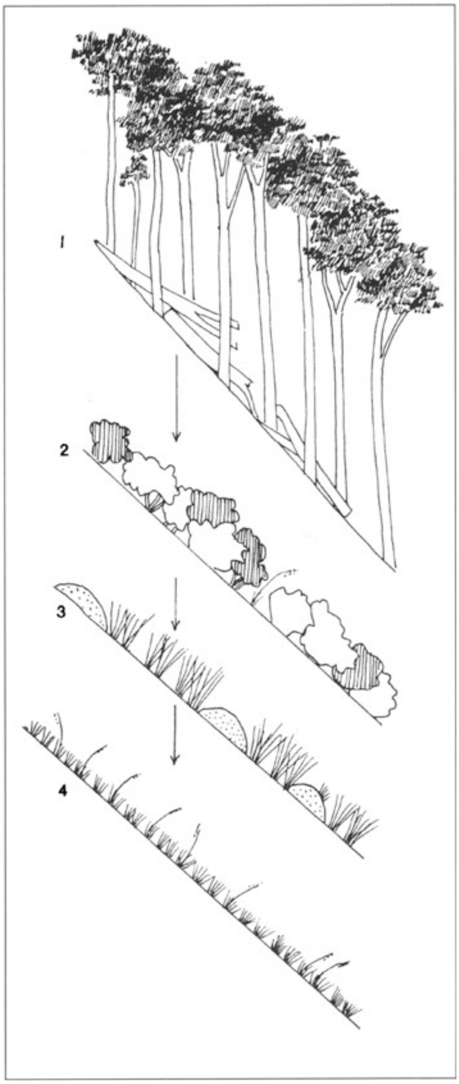

Fig. 12.4 Dynamic processes in the forests of *Nothofagus pumilio*, Patagonia, Argentina; *1* fluctuation in forest of *Mayteno-Nothofagetum pumilionis*; *2* forest regression due to wood cutting, grazing and fire-matorral of *Elymo-Chiliotrichetum*; *3* pajonal of *Stipo-Mulinetum spinosi*; *4* grassland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

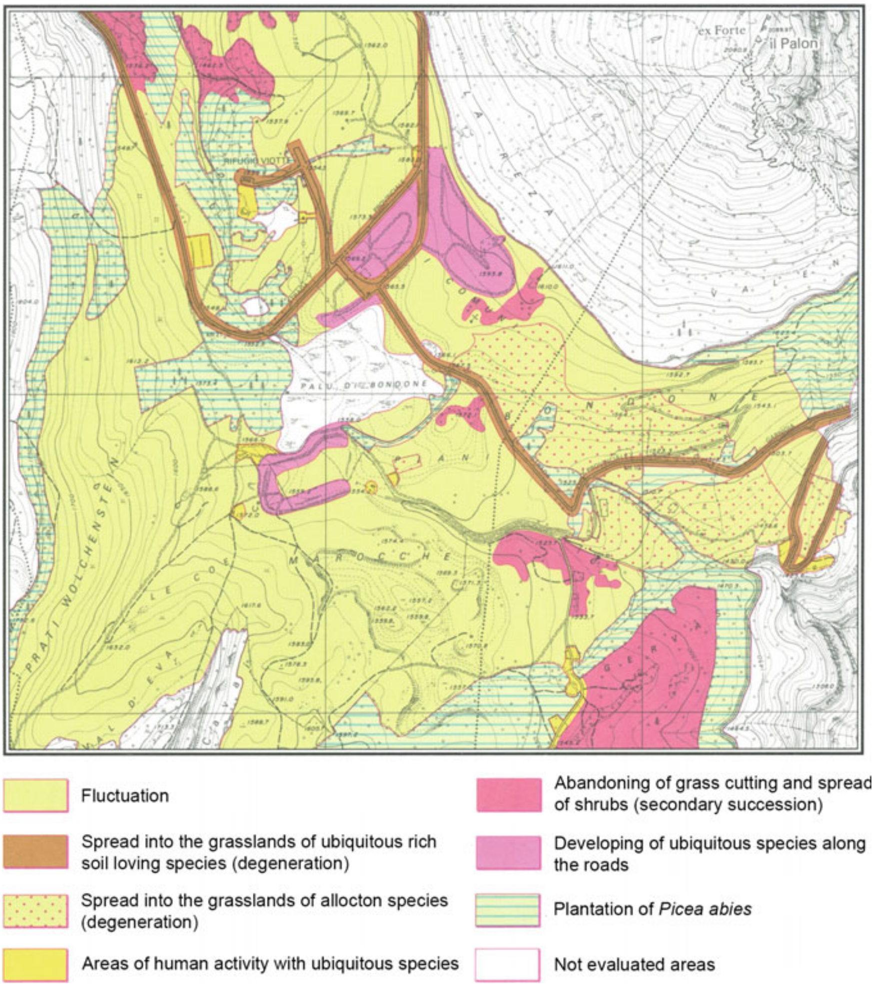

Fig. 12.5 Dynamic processes in the meadows of Viotte del Monte Bondone, Trentino, Northern Italy (from Pedrotti 1996)

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.

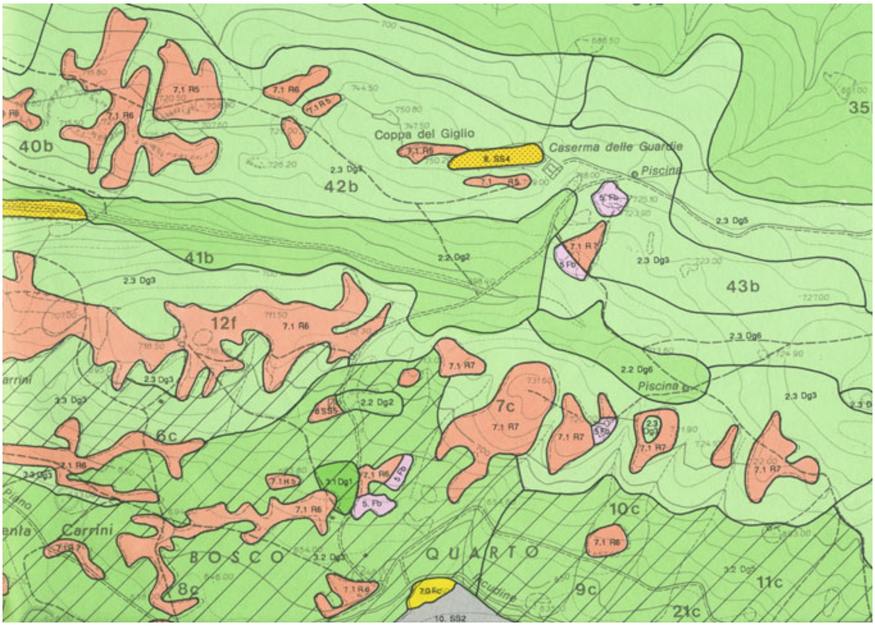

Fig. 12.6 A sector of the vegetation map of the "Bosco Quarto", Gargano, Apulia, Southern Italy. *Green colors* indicates forest associations, among which the *Doronico-Carpinetum betuli*; in the valley bottom, forest is continuous whereas on the slopes is interrupted by numerous clearings (in *red*)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

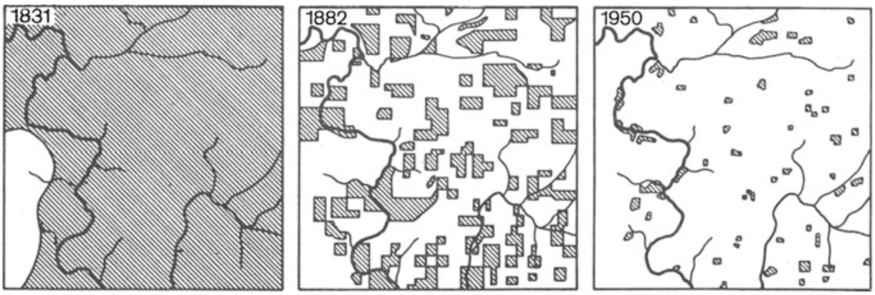

Fig. 12.7 Maps of parceling, fragmentation and disappearance of a forest in Wisconsin, USA (from Faliński 1998)

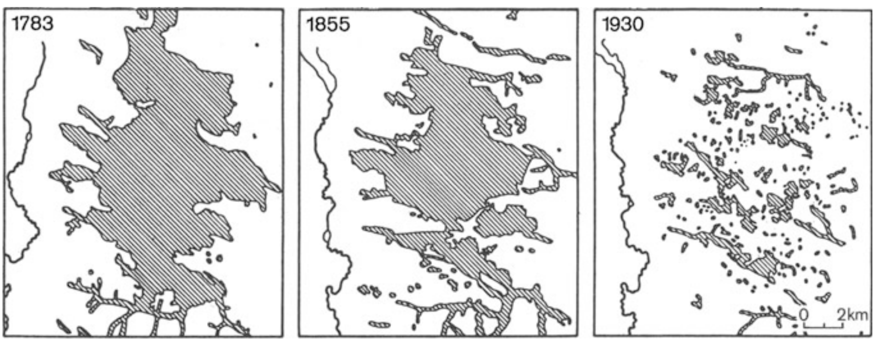

Fig. 12.8 Maps of parceling, fragmentation and disappearance of a steppe in Ukraine (from Faliński 1998)

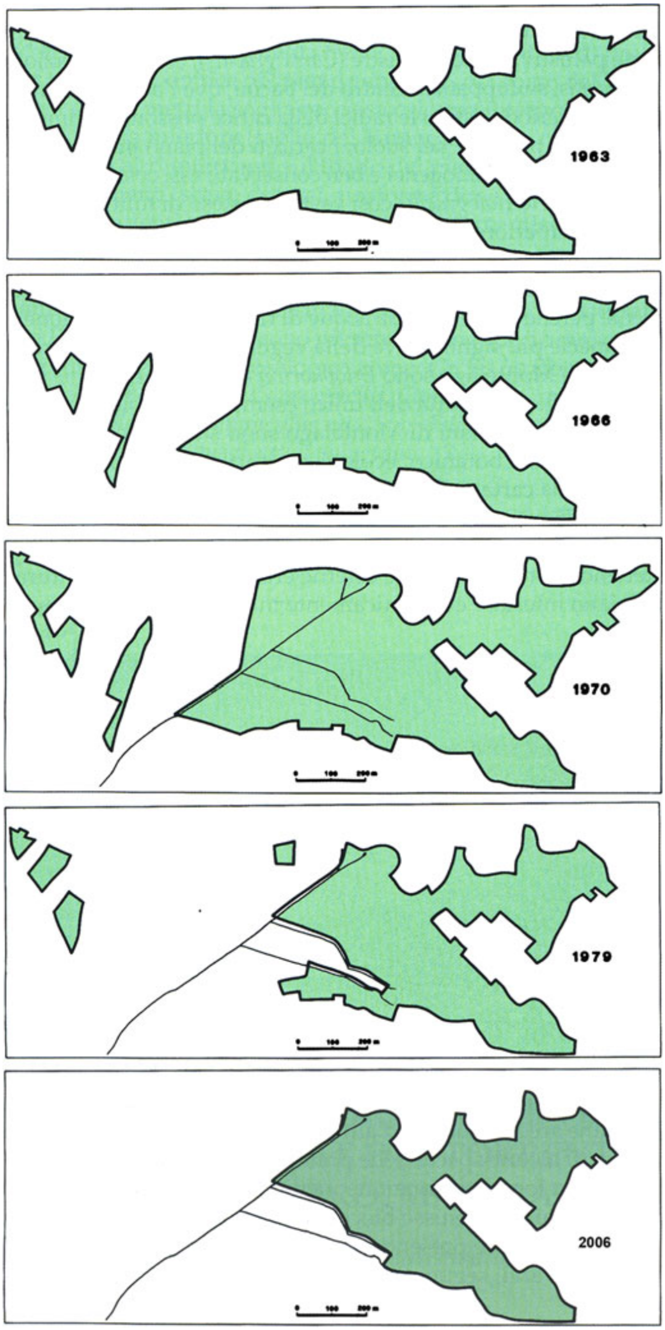

Fig. 12.9 Maps of parceling, fragmentation and disappearance of the grasslands of Piano di Montelago, Camerino, Marche (among which *Hordeo-Ranunculetum velutini*), following tillage interventions (survey by F. Pedrotti)

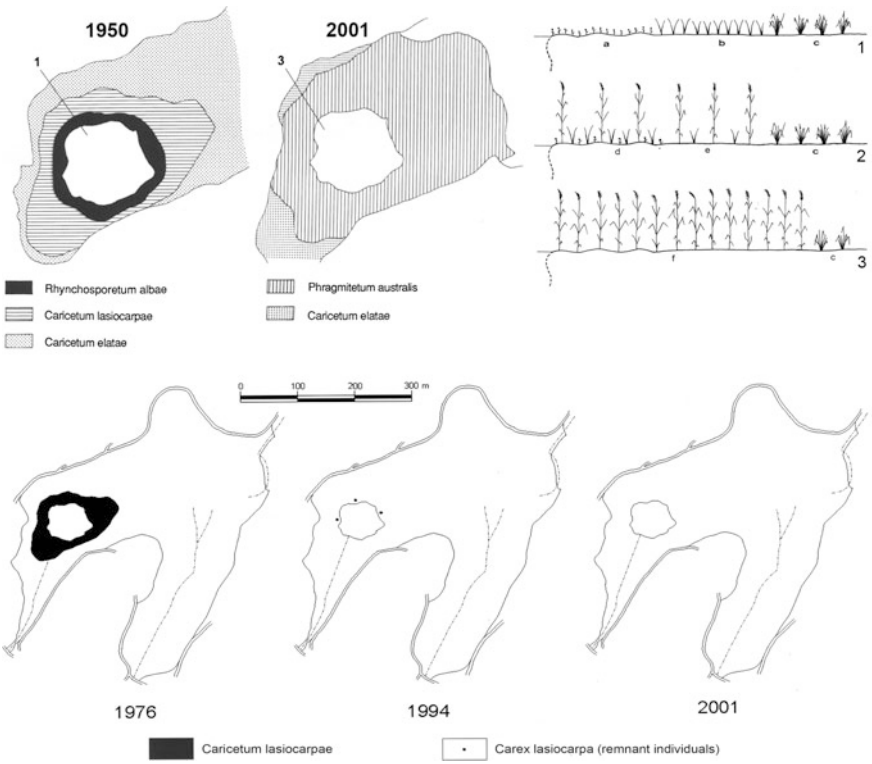

Fig. 12.10 Progressive reduction and disappearance of a few peatland and swamp associations in the Laghestel di Piné (Trentino, Northern Italy). *Top* from 1950 to 2001, disappearance of *Rhynchosporetum albae* and *Caricetum lasiocarpae* and strong expansion of *Phragmites australis*; *a—Rhynchosporetum 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.

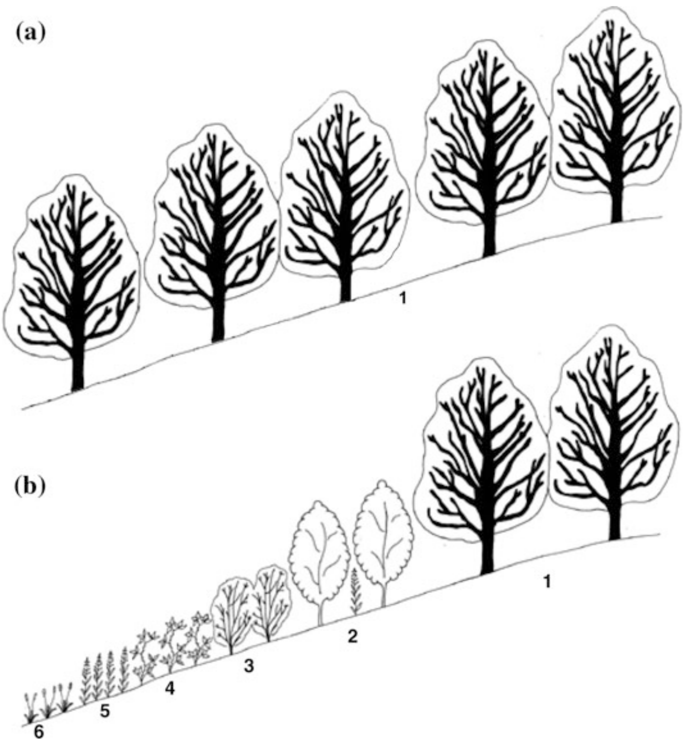

Fig. 12.13 **a** Vegetation series of *Fagus sylvatica* (*Cardamino pentaphyllo—Fageto* sigmetum), Monte Bondone, Trentino, Northern Italy; here only the more mature association, i.e., the forest, is showed. **b**—the same series with all the associations included *1*—forest (*Cardamino pentaphyllo-Fagetum*), *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,

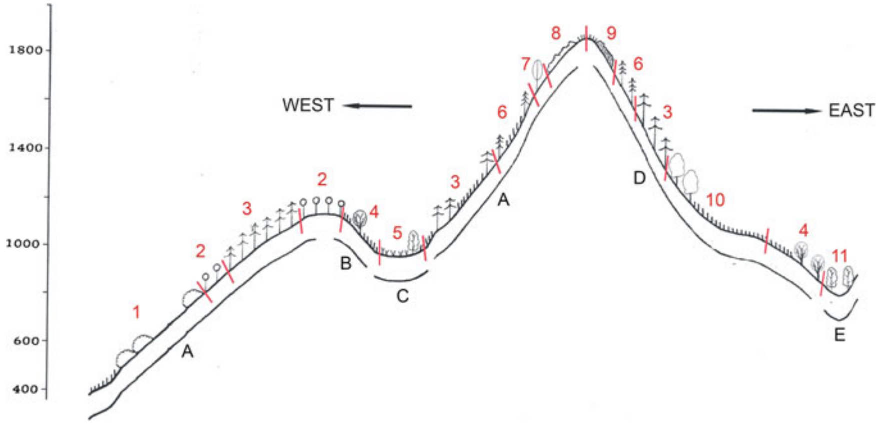

Fig. 12.14 Spatial relationships among vegetation series and geoseries, Piné, Trentino, Northern Italy; series (sigmeta): *1—Fraxinus ornus* and *Ostrya carpinifolia* series [*Fraxino orni-Ostryeto carpinifoliae* sigmetum], also formed by the *Tunico-Koelerietum gracilis* association; *2—Pinus sylvestris* 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)

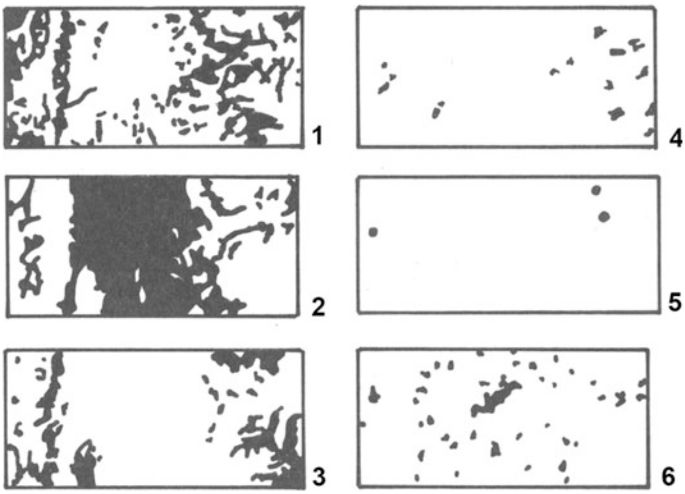

Fig. 12.16 Anthropic impact on the Camerino territory, central Apennine. Each type of disturbance is represented by a different map: *1*—Coppiced woodlands of deciduous trees (which are currently undergoing a process of fragmentation); *2*—cultivated areas; *3*—mountain pastures; *4*—reforested zones;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

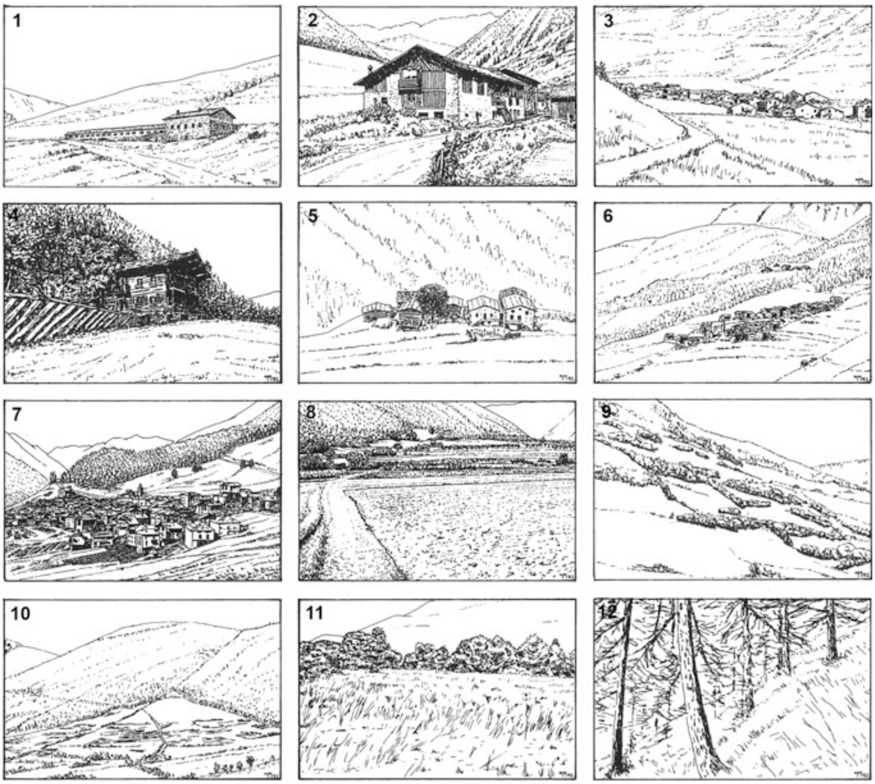

Fig. 12.17 Environmental units of the Stelvio National Park, central Alps: *1*—"malghe" and surrounding grazing clearings, *2*—temporary "masi" and surrounding lawn clearings; *3*—temporary villages for summer use; *4*—permanent houses and surrounding grazing and lawn areas *5*—built-up areas and surrounding 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,

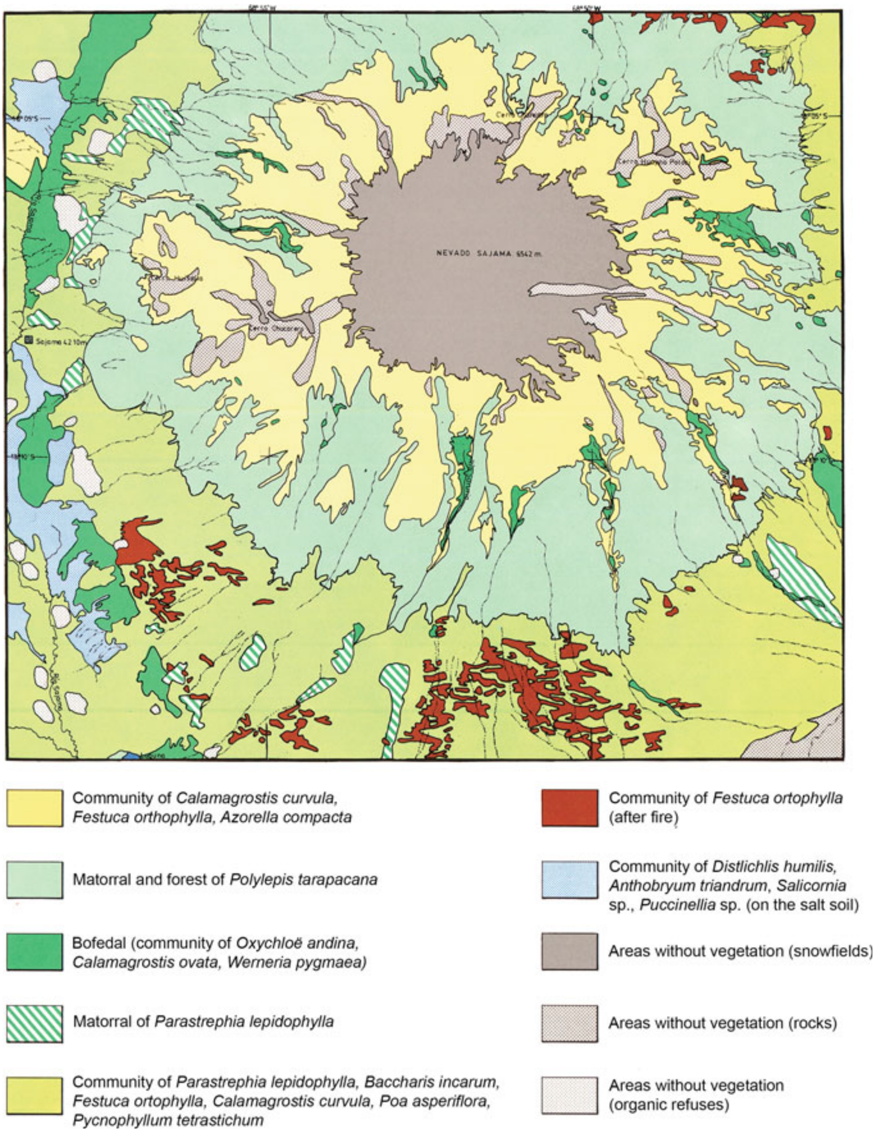

Fig. 12.18 Vegetation map of Nevado Sajama, an extinct volcano in the Bolivia's highland plateau; vegetation tend to develop on the volcanic cone in concentric rings. The matorral belt of *Polylepis tarapacana* is clearly shown. It is interrupted by lava flows and deposits of volcanic debris on which 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)

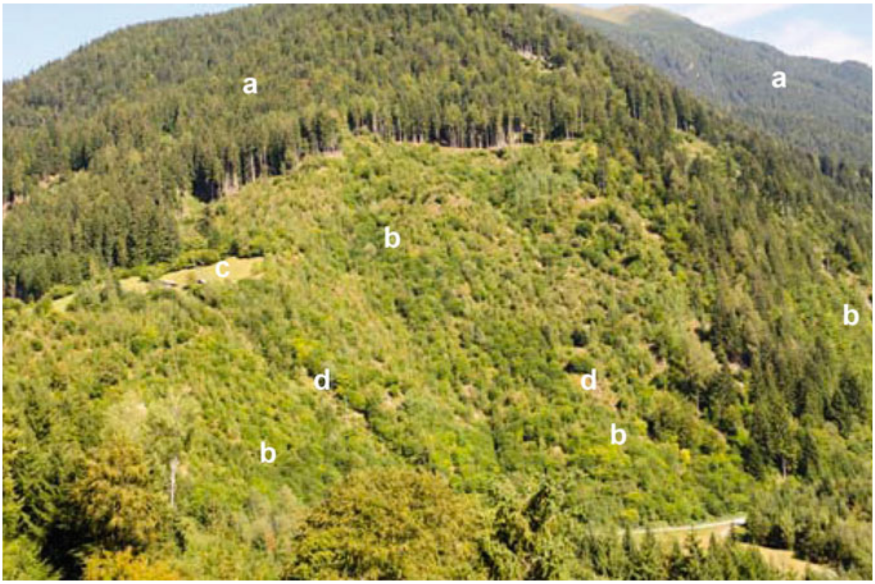

Fig. 12.19 Val Calamento, in the Trentino (Northern Italy). Clearing caused by a whirlwind in the mountain forests of *Picea abies* belonging to the *Luzulo-Piceetum* association (*a*); shrublands of *Rubus idaeus* (*Rubetum idaei*) and *Salix caprea* (*Salicetum capreae*) have developed; (*b*) letter (*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

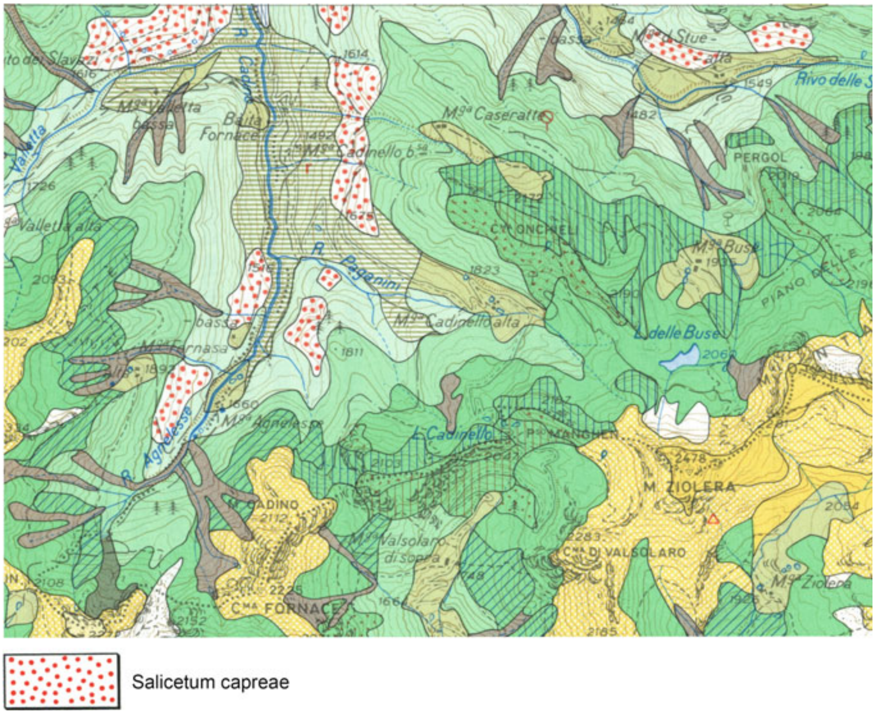

Fig. 12.20 Vegetation map of Val Cadino, Lagorai (Trentino, Northern Italy); in the areas where a big storm has destroyed the tree layer of the original forest corresponding to *Luzulo-Piceetum*, a *Salicetum capreae* association has developed (from Pedrotti 1988)

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).

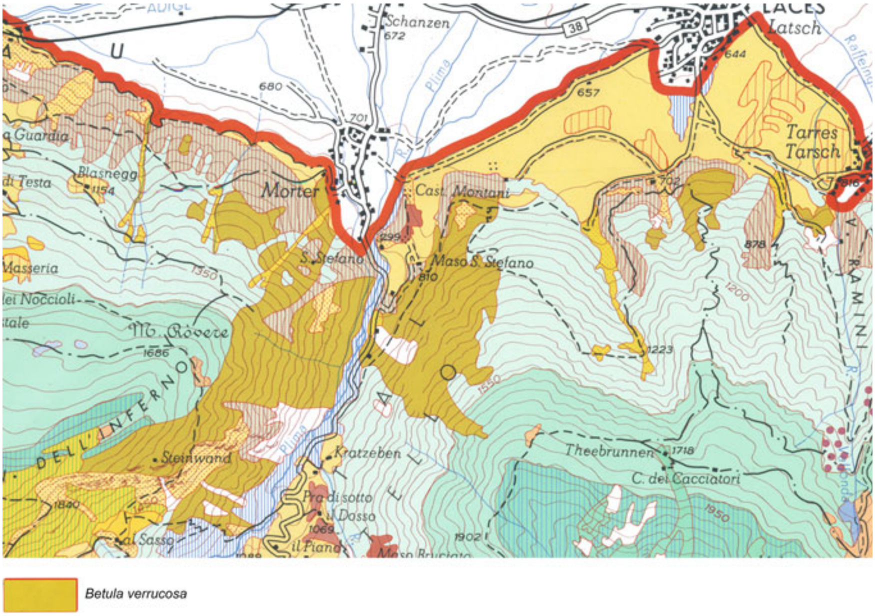

Fig. 12.21 Vegetation map of the Stelvio National Park, central Alps; in the areas affected by forest fires *Betula verrucosa* has grown (from Pedrotti et al. 1974)

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

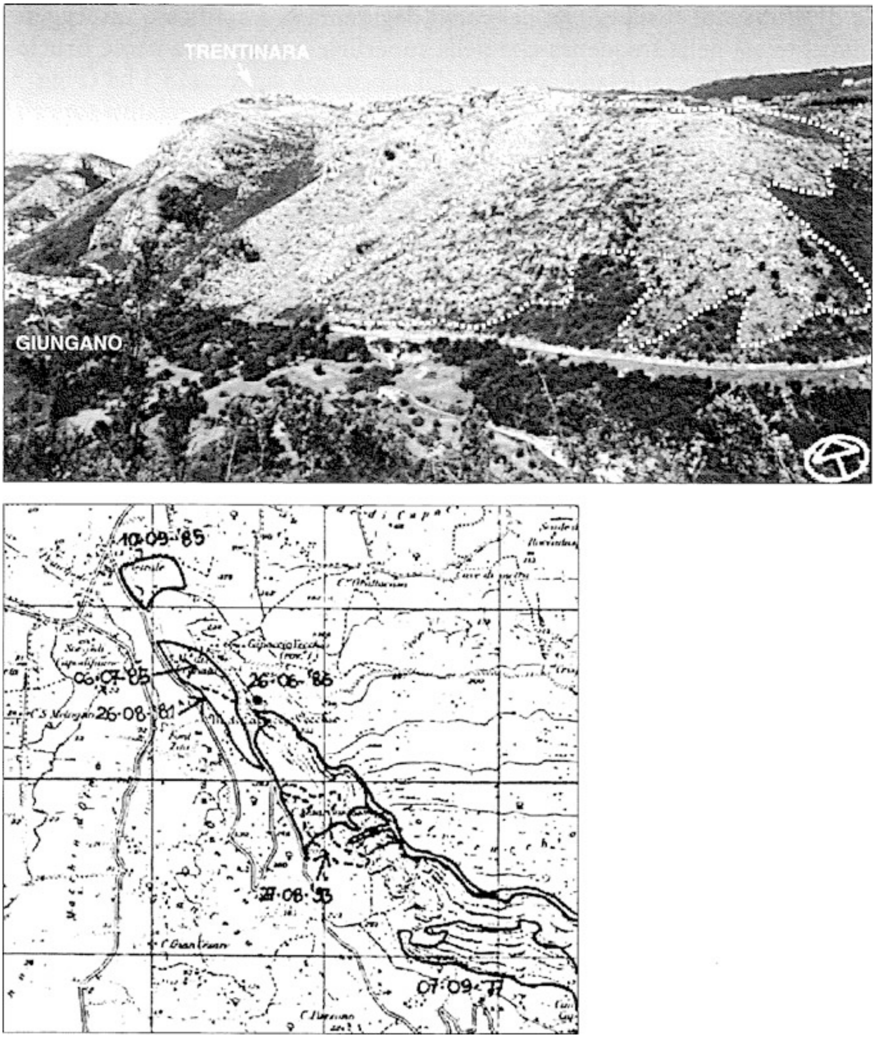

Fig. 12.22 Contour line of fires reported on the map, Campania, Southern Italy (from Mazzoleni et al. 2001)

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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Chapter 13
Including Threats in Adaptive Management

Conservation Action Planning (CAP) has been developed by the international organization known as The Nature Conservancy as a model of adaptive management dedicated to professionals in the field of conservation biology and environmental management. It constitutes one of the three main models supporting the TNC strategic framework called Conservation by Design (TNC 2000 and subsequent documents) to which we refer you for further reading.[1]

The CAP model has been developed in order to define appropriate strategies for preserving key targets (species, communities, ecosystems, and processes) in specific conservation sites. It has been applied by TNC in reserves and in other conservation sites around the world. It has also been adapted and applied by WWF and many NGOs and government agencies.[2]

The basic assumption of this approach relies on the concept of *adaptive management* carried out through the application of constant monitoring programs which assess the effectiveness of the actions taken on specific conservation sites. The CAP model can be applied by a project team whose work is arranged according to a series of different steps aimed at better developing the actions needed to achieve the conservation goals.[3]

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[1]The other two major models are the *Major Habitat Assessment* and the *Eco-regional Assessment*. They are mainly focused on the selection of objectives and priorities, whereas CAP is mainly based on the choice of the most appropriate strategy useful for achieving the objectives. However, as far as result assessment is concerned, the three models all share similar aspects (Esselman 2007).

[2]Such an approach is contained in the *Open Standards for the Practice of Conservation* (aka, *Open Standards*) which has been defined thanks to the support of the major associations and government agencies around the world. Information and materials are available on http://www.conservationmeasures.org. Interestingly, the Open Standards methodology entails a specific software called Miradi which is capable of handling all information concerning a given project in a dynamic and coherent way. It can also prove a useful tool to share the project findings at various levels.

[3]The main steps are the following: *project scope*, *focal elements*, *stress and source*, *strategy*, *success* (see the box in this section).

C. Battisti et al., *An Introduction to Disturbance Ecology*,
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CAP is performed by assessing the context constituted by biodiversity values and threats and the results obtained in terms of management effectiveness and efficiency. All this is integrated into an extensive process including specific strategies development and application (Hockings et al. 2000 and subsequent documents).

In the evaluation process the main and most relevant steps can be identified as follows:

(i) Clear definition of conservation targets, of their *status* or *condition* and intervention priorities setting;
(ii) Identification and rating of *threats* to priority targets;
(iii) Monitoring or using other methodologies to gain information on the current conservation status of the targets;
(iv) Applying the findings to the management of the site through a process of adaptive management.

The following box shows the overall process which, as indicated in point 4., includes a step pertaining to the subject of this book (identification of priority threats, here defined as *critical threats*; TNC 2000). This schematic summary can be useful to define the management procedure of a site.

A. **Project definition**

1. **Identifying the technicians involved in the project**

    - Selecting a core project team and assigning roles
    - Identifying other planning teams, consultants, or advisors as needed
    - Identifying a leader

2. **Defining project *scope* and conservation *targets* (project scope stage)**

    - A short descriptive text and map or the area of interest
    - A statement of the overall vision of the project
    - Selection of targets (not more than 8) and explanation of the choices made

B. **Rating of targets and threats and definition of the conservation strategy (system focal elements stage)**

3. **Viability rating of selected targets**

    - Selection of at least one key ecological attribute and one indicator for each target
    - Definition of an acceptable variation range for each attribute
    - Determining the current and desired status of each attribute
    - Brief documentation of viability assessments and any important research needs

4. **Identification of critical threats (stresses and sources stage)**
    - Identification and rating of the stresses affecting each target
    - Identification and rating of the stress source for each target
    - Determination of critical threats
5. **Development of conservation strategies (strategies stage)**
    - Performing a situation analysis including indirect threats, opportunities, and stakeholders
    - Highlighting (by writing a text or graphically) the hypothesized links among indirect threats, direct threats, opportunities, and affected targets: defining causal chains for each relation target/threat
    - Defining specific objectives for each threat or attribute of the target and, if deemed useful, for each factor directly or indirectly associated with the project success
    - Defining one or more strategic actions for each conservation target
6. **Identifying the monitoring tools (success stage)**
    - Compiling a list of indicators and methods to assess the status of selected targets and threats which are currently under study
    - Compiling a list of indicators and methods to verify the effectiveness of each conservation action

C. **Applying conservation and monitoring strategies**

7. **Developing work plans**
    - Compiling a list of actions and monitoring modalities
    - Task assignment to specific individuals; determination of a timeline
    - Brief summary of project capacity and a rough project budget
    - If necessary, specifying objectives and actions for obtaining sufficient project resources
8. **Implement**
    - Actions
    - Monitoring

D. **Utilizing results to adapt and improve**

9. **Analyzing, updating, and modifying**
    - Appropriate data analysis
    - Possible updating of project feasibility and threat rating
10. **Learning and sharing**
    - Identification of the most appropriate audience and communication methods

In situations of high uncertainty, time, and resource limitation, it may not be possible to obtain data from original samplings. Therefore, in such a case it is necessary to rely on expert-based approaches. To such an end, in the CAP process a specific evaluation system based on scores has been applied in many contexts.

Initially the project team's task consists of the definition of conservation targets and key values, by identifying key ecological attributes and indicators for each target. In the CAP process, the attention is focused on conservation targets, i.e., on populations, species, communities, and ecological systems chosen to better represent and comprise the biodiversity of a site (e.g., protected areas, or other sites of conservation importance, such as the Natura 2000 sites). Targets constitute the fundamental components to set objectives, implement strategic actions, and to assess conservation project effectiveness. Targets can be considered the most important strategy goals, or, from a more generic point of view, they can be treated as indicators. In the latter case the assumption is that, by preserving selected targets, the conservation of a large part of the biodiversity present in a site or territorial area could also be ensured. So, targets will have to be as representative (focal) as possible at different spatial and temporal scales (TNC 2007). It is advisable to select them from coarse-grained categories (e.g., communities or ecosystems) and then progressively chosen among those 'nested' into broader categories (e.g., individual species belonging to communities or individual communities included into ecosystems).

Each target has its own characteristics, here defined as key ecological attributes (KEAs), which can be utilized to define and assess its viability and integrity. In general, such attributes are outstanding and critical characteristics of target ecology and biology, which, if lacking or modified, are likely to cause target extinction in the short-medium term. Each ecological attribute can be measured either directly or indirectly by indicators (Parrish et al. 2003; TNC 2007). For KEAs and indicators an acceptable variation range needs to be defined.[4]

Detailed instructions to implement this method are provided in training courses and materials are available on the Internet. The Excel CAP sheet, also available online, is a useful tool for implementing the general framework. It contains instructions, tips, and examples useful for analyzing information.

[4]Also utilizing categories, such as for example: *Very Good* (the indicator functions within an excellent ecological scenario and needs little intervention to maintain its status within its natural range of variation); *Good* (the indicator is functioning within its natural range of variation, although it may require some intervention for its maintenance); *Fair* (the indicator lies outside of its natural range and requires intervention for its maintenance; if unchecked it will be vulnerable to serious degradation); *Poor* (allowing the indicator to remain in this condition for an extended period will make it impossible to get it back to an acceptable condition—because the process would be too complicated, costly, or simply not reversible).

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Chapter 14
Conclusions and Prospects

Wildlife management is evolving from an art form to a science.
Perhaps it will never become a science,
but every effort should be made to encourage this evolution.
(Giles 1978)

In this book the fundamental concepts of disturbance ecology have been presented. Such concepts have allowed us to deal with the subject concerning the consequences of human-induced events from a new perspective, particularly by considering their importance in management and conservation strategies.

Threat analysis is a new discipline which can be useful to the managers of protected areas or other natural sites; it can also be used by practitioners who have to fulfill specific conservation projects dedicated to species, habitat types, and environmental components.

It has been pointed out throughout the book that anthropogenic disturbance events form a part of a causal chain linking the main driving forces, through indirect threats, up to the threats directly acting on the targets. Since such relations are recurrent, albeit sometimes very articulated and complex, their modeling can be performed through simple theoretical frameworks.

The importance of assigning a standardized nomenclature to the threat events has also been highlighted. It enables us to easily diagnose and place threat events into a universal system of classification, similar to the one currently used in biological systematic and taxonomy, which can be utilized in many different conditions and contexts. Such a hierarchical system turns out to be a useful tool for those who manage sites and targets of conservation concern. In fact, it enables them to identify the most relevant characteristics of the threat events and their similarities on the basis of the group type (family, genus) to which the event itself is assigned.

In a subsequent phase, threat analysis will make it possible to quantify and compare threat events in a quick and easy way (through scoring, rating and ranking) on the basis of their respective regime attributes (frequency, intensity, duration, extent and, ultimately, magnitude). This constitutes an important procedure, particularly when dealing with sites where more events occur at the same time: in this case deciding which one should be considered as a priority is of particular

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significance. Comparisons allow us to identify the threats which are most in need of urgent strategies, although it should be remembered that, in general, such operations are carried out in conditions of limited time, financial resources, and staff availability. Only after having promptly defined a priority order, on the basis of an expert-based methodology, the individual threat will be analytically studied utilizing approaches, protocols, tools, and metrics specific to the particular event type (be it physical, chemical, or biological).

The tools provided by threat analysis also enable us to evaluate, in a quick and easy way, the effectiveness of interventions and strategies performed by the project team.

In contrast to the approach utilized by the IUCN red lists, in which threat description is centered on the threatened species (see www.iucnredlist.org) and where species-based strategies are crucial (e.g., by action plans), in threat analysis species are only considered as one of the possible hierarchical levels which can be impacted by a threat event (site-based strategy). Indeed, among those who are in charge of conservation concern sites, it is well known that human-induced factors and processes act on the territory they manage. The effects exerted by such activities are felt, often at the same time and transversally, by various components (individuals, populations, communities, ecosystems, landscapes, and ecological processes) which are all possible conservation targets. According to a site-based approach, besides individual species, threat analysis can thus be applied also to other environmental values belonging to a site. As far as management processes are concerned, this type of approach can be important in many conservation sites (Natura 2000 sites, protected areas).

At the same time, the limits of such an approach should also be pointed out, as briefly discussed below:

- first of all, in management strategies, this approach can be applied to classify, quantify and compare threats acting in relatively small areas (protected areas, Natura 2000 sites). On performing threat analysis at a wider scale (for example, in the case of environmental fragmentation and global warming), other approaches need to be utilized. However, in threat analysis, such mega-threats can be considered as indirect threats capable of triggering many events on a local scale.
- Threat analysis constitutes a coarse-grained approach. Through the definition of certain standards and procedures, it allows the definition, in a schematic and theoretical way, of terminology and problems which will have to be tackled in site management, also making their comparison easier and thus facilitating the identification of priorities. However, a point of weakness should also be mentioned, i.e., threat analysis is not devoted to dealing with the individual events from an analytical perspective. The analytic measurement of individual threats (not their expert-based evaluation) constitutes a subsequent step which will be carried out by practitioners specialized in the individual factors and processes. They will utilize specific technical procedures, metrics, indicators, and units of

measurement according to a fine-grained approach. For a more in depth analysis, we refer you to the wide scientific literature on the subject.

Moreover, although the building of conceptual frameworks turns out to be useful as a modeling tool, since it facilitates the identification of the relations between targets and threats, it should be mentioned that, in any case, it represents an oversimplification of real-world complexity (and lack of linearity).

This book is merely an introduction to the subject of threat analysis. Many of the aspects, which have been mentioned so far, need to be further investigated and a debate is still going on in leading conservation journals. For this reason, here is an overview of the issues requiring further investigation:

– As far as the third hierarchical level ('species' of threat) is concerned, the process of threat classification also needs to be implemented. Since the events are often extremely localized and originate from historical processes, biological and anthropogenic relations which are specific to individual sites, classification at this level may be difficult to realize and it may take more time to be developed. In this respect, specific classifications based on geographical criteria might be hypothesized (at a national and regional level or at the level of biogeographic regions); alternatively, a third-level examination might be performed only on certain threat categories (e.g., those pertaining to urbanization, agriculture, marine harvesting, etc.) or ecosystem types (e.g., forest areas, wetlands, coastal areas, etc.).
– The question presented by Balmford et al. (2009) and criticized by Salafsky et al. (2009) needs to be resolved. The IUCN-CMP classification includes both *stress factors* and *mechanisms*, without considering the identification of the causal issues, as it was suggested by Balmford and colleagues. As far as stresses are concerned, IUCN-CMP classification is apparently also inadequate and in some cases contradictory (see Balmford et al. 2009). Further research, carried out by specific work teams (in Italy within public research groups such as the Institute for Environmental Protection and Research, ISPRA) might provide an integration of the two approaches.
– In threat analysis, scores are assigned according to expert-based approach. The experts need to be well informed in order to ground their inferences on reliable data. Currently, because of the obvious difficulties characterizing management procedures (suffering from a limitation of means, time and financial resources), many studies aimed at defining the regime of one or more threats are carried out over small periods of time, within restricted, non-representative areas, and with an insufficient number of repetitions. It is known that disturbance regimes may be affected by stochasticity (unpredictability) and therefore a regular trend is not observable in the short term. Research on disturbance regimes should be carried out at the territorial level (for example within Park Agencies) with standardized, repeated, representative, independent samplings (see Battisti et al. 2014). In such a way, the expert-based approaches will be grounded on more reliable

information which over time will replace the expert-based scoring system, potentially affected by subjectivity bias.

– Operative handbooks might be written to provide useful and synthetic information to the managers of valuable sites for nature conservation. They might be helpful in characterizing, classifying, and quantifying threats to the local sites. An illustrated atlas and informative sketches about threats to specific ecosystems might be published in a similar way to the descriptive sketches providing synthetic information about the species and habitats listed in the Annexes of the European Directives.
– Compilations of threat check-lists should be proposed for protected areas, Natura 2000 sites, reserves managed by ONG, etc. In such a way, the presence of recurrent patterns might be assessed and mitigation strategies on a large scale might be defined (see the paper by Teofili et al. 2006, who reviewed the threats to 760 Italian sites of the Natura 2000 network).
– Threat mapping (drawing on GIS methodologies) should also be encouraged. The best way of mapping dynamic, inconstant, unpredictable, and uncertain events, which cannot easily be represented with polygons (or other forms and symbols) on informative layers is still an open issue.
– The procedures of threat rating and ranking are extremely straightforward (e.g., based on algebraic sums) and allow quick evaluation and comparison of a high number of events occurring simultaneously in a given site. However, for certain attributes of threat regime multiplication coefficients may be used in order to make the evaluation more solid and reliable. Currently, the scores assigned to *frequency*, *duration*, *intensity*, *extent*, etc. all have the same range (e.g., from 1 to 4) and the weight assigned to each score is the same for every attribute (i.e., it is assumed that the weight of the score for a given attribute, e.g., *frequency*, is comparable to the weight of the score for another attribute, e.g., *intensity*). The validity of such assumptions should be tested and if necessary, multiplicative coefficients should be employed.
– Since several classification systems are available (e.g., IUCN and Habitats Directive), documents comparing different nomenclatures are needed (using the 'Rosetta Stone' analytical approach, see Teofili and Battisti 2011).
– The issue concerning impact and pressure indicators (within the DPSIR approach) should be expanded and a classification of the most effective indicators for certain threat events should be envisaged. Such classification might be available for the managers in the form of an operative guide manual. The Italian Association of Environmental Analysts has given its contribution to this issue (see also ARPA Piemonte 2008). In future, it will be possible to select a set of pressure indicators at least for the most important threat categories or types, together with a set of impact indicators, at least for the most sensitive environmental components and/or the most frequent in this type of analysis (e.g., habitat types according to Directive 92/43/EEC).
– The normative and preparation procedures of planning tools used in protected areas and in the sites of community importance (as in Management Plans) as well as the normative and preparation procedures of other environmental

planning tools (Forest Management Plans, River Basin Management Plan, etc.) should entail a step dedicated to threat analysis;

– Training opportunities should be provided to managers of protected areas and of territorial Agencies coming from different disciplines (naturalists, biologists, agronomist, forest scientists, geologists, environmental economists, urban planners, environmental engineers, sociologists, psychologists, historians, and others). The training should be centered on the transversal issues of disturbance ecology and threat analysis (nomenclature, quantification, comparison, rating).
– At the academic level, students should be encouraged to write theses and dissertations about these issues. Specific modules might be made available in courses of applied ecology, ecosystem management, environmental impact assessment, and others.
– Finally, the conceptual framework of this field might be improved by receiving the methodological contribution of different but related disciplines (problem solving, decision-making, risk analysis; see Harwood 2000; Burgman 2005; Gandolfi 2012).

Threat analysis approach may be an opportunity for private and public agencies in charge of protected areas and sites of conservation concern. In fact, it highlights the significant role played by such agencies in monitoring territories and in the assessment of the natural and anthropogenic processes. In those areas, thanks to such territorial units, it is possible to carry out uninterrupted and analytical research on the spatial–temporal regime of disturbances using internal resources and staff. In fact, such events are strictly linked to the particular history, conditions, and natural and anthropogenic components of the site itself (see Battisti and Forti 2010). After acquiring suitable operating tools and endowing with a team of experts trained in this field, the agencies could present themselves as institutions for applied research and collaborate with universities and other research groups.

The tools and technical methodologies in use by environmental management scientists are becoming more and more standardized. This will allow them to overcome the trial and error approach which has characterized the management of natural sites in the last few decades. This new approach will help to start a process of adaptive management according to defined criteria and coherent procedures, suitable to deal with the complexity of the ecological processes.

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