BIODIVERSITY CONSERVATION AND HABITAT MANAGEMENT: AN OVERVIEW

Francesca Gherardi
Dipartimento di Biologia Animale e Genetica, Università di Firenze, Italy

Claudia Corti
California Academy of Sciences, San Francisco CA, U.S.A.

Manuela Gualtieri
Dipartimento di Scienze Zootecniche, Università di Firenze, Italy

Keywords: Biodiversity, conservation, habitat management, human-induced extinctions, non-indigenous species, threatened species, reserves, supplementation of populations, ecological economics

Contents

Summary

Biodiversity is the wealth of life on earth: the millions of plants, animals, and microorganisms; the genes they contain; and the intricate ecosystems they help build into the living environment. It is under threat from an "Evil Quartet": over-harvesting by humans; habitat destruction and fragmentation; the impact of introduced species; and chains of extinction. Conservation biology, a multidisciplinary science, has developed in recent decades in response to the biodiversity crisis. It has three goals: investigating and describing the diversity of the living world; understanding the effects of human activities on species, communities, and ecosystems; and developing practical interdisciplinary approaches to protecting and restoring biodiversity.

This essay analyzes a number of points that underlie the issues of biodiversity conservation. Its main purposes, however, are to emphasize and describe the various trends or currents that must be combined within each conservation management action. These include:

- increasing our knowledge
- restoring habitats and managing them
- establishing reserves
- supplementing populations
- legally protecting indigenous species
- preventing non-indigenous species invasion
- eradicating pests
- contributing to education and public awareness
- combining conservation with economic development.

Clearly we are in the midst of evolutionary changes that will continue to alter the composition of all biological communities, and the ways in which we manage them. As seems usual in such revolutions, the various pragmatic issues involved will probably overwhelm the ethical ones. Biological complexity will always elude total human comprehension, and the hypothesized solutions for arresting conditions of decay will never seem comprehensive. However, our vision for the future remains optimistic. Science and technology are developing more and more powerful weapons against biodiversity loss, which may operate at different levels (science, education, culture, journalism, economics, and politics). Awareness of environmental issues is great, and conservation is considered important – and even vital – for the wealth and health of our future generations. Ecotherapeutic activities are not simply working hypotheses: serious efforts are under way to make them effective.

1. Introduction: the amount of biological diversity

How great is the earth's biological wealth?

(E. O. Wilson, 1989)

Since 1753, when Carolos Linnaeus proposed the binomial system of nomenclature, 1.5–1.6 million *species* of diversified organisms have been recognized and named in a formal, taxonomic sense. Approximately 750,000 of these are insects, and 250,000 are plants. The remainder consists of other invertebrates, vertebrates, fungi, algae, and microorganisms (Figure 1).

Most systematists agree that this picture is still very incomplete except in the cases of a few well-studied groups (e.g. birds among animals and flowering plants). At least twice the total number of known species remains undescribed: these are primarily insects and other arthropods, especially those inhabiting tropical forests (Figure 2).

Our knowledge of species numbers is imprecise because inconspicuous species, such as spiders, nematodes, and fungi living in the soil, have not received a proper taxonomic attention. In addition, only about 4,000 species of bacteria are recognized by microbiologists: work in progress in Norway has revealed more than 4,000 species in a single gram of soil and a similar number in marine sediments. A second drawback in the description of species comes from insufficient collecting in the marine environment, particularly in the deep sea, and in forests. An entirely new animal phylum, the Loricifera, was first discovered in 1983 when specimens were collected from the deep seas; the Cycliophora, first described in 1995, were based on tiny, ciliate creatures found in the mouthparts of the Norway lobster. Recently, three species of large mammals new to science – now known as the Giant Muntjac, the Vu Quang Ox, and the slow-running deer – were discovered in mountainous rainforests between Vietnam and Laos.

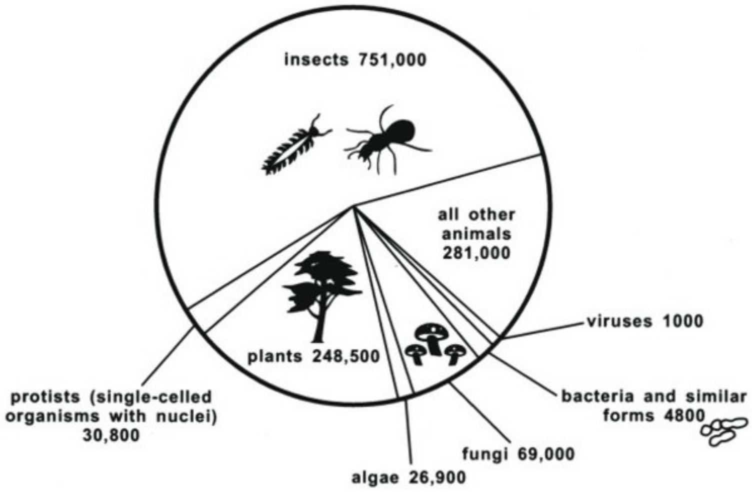

Figure 1. The distribution of the approximately 1,413,000 species described within the different groups of organisms. The majority are insects and plants.

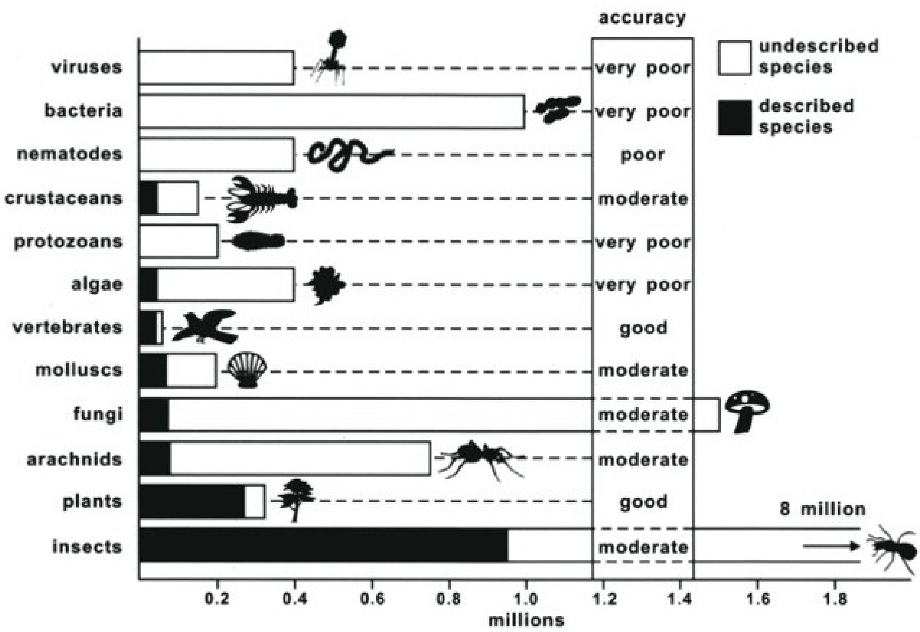

Figure 2. The numbers of described species (indicated by the shaded portions of the bars) and of the assumed undescribed species (indicated by the white portions of the bars). Conservative estimates of the actual number of existing species for those groups of organisms expected to contain in excess of 100,000 species are reported in the column at right.

Each species is a repository for an immense amount of genetic information. The number of genes ranges from about 1,000 in bacteria, through 10,000 in some fungi, to 400,000 or more in many flowering plants and a few animals. Genetic information is found in each cell. It is organized in strings of DNA, each of which comprises about a billion nucleotide pairs. This molecule is invisible to the naked eye because it is only twenty angstroms in diameter. If stretched out, however, the DNA would be around one meter long. Along its length, it is composed of some twenty nucleotide pairs or "letters" of genetic code. The full information contained therein, if translated into ordinary-sized letters of printed text, would just about fill all fifteen editions of the *Encyclopaedia Britannica* published since 1768.

Only part of the biological diversity on the earth is composed of the number of species and the amount of genetic information within a representative organism. Many organisms constitute one single species. For example, the *ca*. 10,000 ant species have been estimated to comprise 10^{15} living individuals at each moment of time. Except in cases of parthenogenesis and identical-twining, virtually no two members of the same species are genetically identical, due to the high level of genetic polymorphism across many of the gene loci. Wide-ranging species consist of multiple breeding populations that display complex patterns of geographical variation in genetic polymorphism. In these cases, even if an endangered species is saved from extinction, it will probably have lost much of its internal diversity. When the populations are allowed to expand again, they will be more genetically uniform than their ancestral populations.

If conservation policy is to be based on a sound knowledge of the genetics, taxonomy, ecology, and behaviour of a species, at present we are capable of managing the evolutionary potential of no more than 100 species. On the other hand, the number of species requiring management is estimated to be closer to 10,000.

2. Diversity in ecosystems

There is a universal tendency to the evolution of dynamic equilibria. The more relatively separate and autonomous the system, the more highly integrated is, and the relatively greater the stability of its dynamic equilibrium.

(A. G. Tansley, 1935)

The most complex ecosystems are markedly unstable, and it is just this continuing instability that allows for the coexistence of their many species. Instability refers here to the degree of change over time in the abundance of the systems components. This may be related to the dynamics of the environment, or to internal feedback mechanisms which condition the system under pressures from the environment. Two examples, from the African wildlife systems and the Australian arid grazing systems, may be cited.

2.1. African wildlife systems

One prototype of the African wildlife systems is the central Savuti channel of northern Botswana’s Chobe National Park. The general structure of the system is shown in Figure 3.

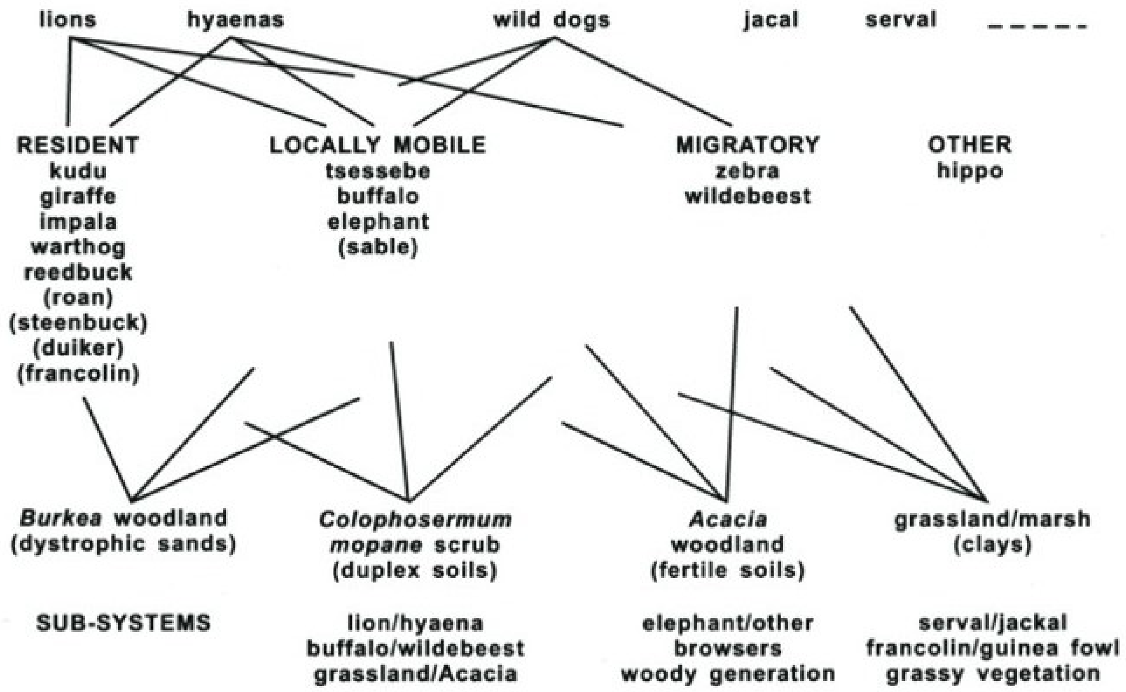

Figure 3. Structure of the central Chobe National Park ecosystem.

Features allowing for a high diversity of ungulate species are as follows:

- The system is spatially very diverse, with animals using different parts at different times.
- It is an open system, into and out of which there is considerable movement of migratory species. On the 100 km^2 of the central Savuti grassland, animal numbers vary annually from virtually zero (for all species) to 16,500 zebra, 2,500 buffalo, 1,500 Tsessebe, and 600 wildebeest. Zebra and buffalo are there during the rain season and Tsessebe during the dry season, while wildebeest are more variable. Elephant numbers can be high, depending on the availability of surface water.
- The strength of biological interactions is variable, and often weak. Feeding overlap and resource competition between species are impossible to estimate, due either to species moving out of the area, or to sudden influxes of large numbers of other ungulates. Predation is opportunistic; environmental conditions are never constant for long enough to permit strong biological interactions to develop.
- The system is driven by external, episodic events, e.g. the supply of surface water in the Savuti Channel, drought, fire, and disease.

The size structure of *Acacia* woodlands, the preferred habitats for both ungulates and tourists, indicates that these woodlands are unstable under pressure from changing population dynamics and are declining. There is no regeneration due to the high browsing pressure by a large variety of animals; the stands of acacias consist of mature, even-aged trees, which are dying as a result of old age and elephant damage. During the early twentieth century the woodland became established when two rare events coincided; the channel dried up and the rinderpest epidemic decimated many ungulate species. Elephants were not affected by rinderpest, but were reduced in numbers by hunting. These combined events reduced the browsing pressure for long enough to allow the extensive stands of acacias to develop.

The coincidence between abundant elephants and the extensive *Acacia* woodlands that we observe today seems unsustainable. Culling elephants is unlikely to lead to regeneration of the woodlands. Both the elephants and other browsers that select young acacias would need to be reduced to very low levels for the required establishment phase. The question is whether the managers and tourists are prepared to accept a 10 to 15 year period when there are virtually no animals to see. However, we still do not know enough about the dynamics of *Acacia* spp. Possibly, there are combinations of conditions (rainfall, lack of fire, spatial movements of ungulates) that would permit regeneration at moderate ungulate levels. This example highlights the need to recognize the importance of *episodic* events when contemplating management intervention in this type of system.

2.2. Australian arid grazing systems

The Kinchega National Park of New South Wales is a fenced area of 440 km^2, with a mean annual rainfall of 235 mm. The vegetation mainly consists of *Atriplex* species and Chenopodiaceae scrub, along with shrub areas, mainly of *Mareana* sp. The herbaceous layer is a mixture of annual grasses and forbs. There are two common kangaroos, the Red Kangaroo (*Macropus rufus*) and Western Gray Kangaroo (*Macropus fuliginosus*); and two uncommon, the Eastern Gray Kangaroo (*Macropus giganteus*) and the Wallaroo (*Macropus robustus*). All four are of similar size. The two uncommon species are limited by habitat association. The response functions between vegetation biomass and kangaroos, and between the latter and rainfall, can be described as follows:

- The system is strongly interactive and seems to be strongly regulated internally. The relation between pasture biomass and rates of change in the kangaroos is strong and rapid. Only the change in actual kangaroo numbers appears not to be dependent on vegetation. The net effect is a very nonlinear system, due to variable rainfall. If rainfall is constant, the system comes rapidly to equilibrium. The system is therefore one in which the dynamics are strongly directed towards a target, but a target which is constantly moving.
- The very low constancy of vegetation has no effect on the diversity of large herbivores, and vice versa. The relations between stability and diversity are unimportant, and are not an issue in the conservation management of Kinchega.
- Studies from any five-year period, taken on its own, would give a completely erroneous impression of the dynamics and "trends" of the kangaroos, and would probably lead to inappropriate management responses.

3. Measures of biodiversity

There is simply not enough money, labour, and expertise to identify, count, and map the distribution of every species in every *taxon* at a global scale in time frames that can assist current conservation decisions. Thus, conservation biologists have been engaged for some time in attempting to find non-census indicator methods that can rapidly and reliably identify areas with disproportionately high levels of biodiversity.

(F. Van Dyke, 2003)

Biological diversity has been defined by the World Wildlife Fund as "the wealth of life on earth, the millions of plants, animals, and microorganisms, the genes they contain, and the intricate ecosystems they help build into the living environment." This means that biological diversity needs to be considered and measured at three distinct levels. First, biological diversity at the species level has to be analyzed across the full range of organisms on the earth, from bacteria and protists through the multicellular kingdoms of plants, animals, and fungi. Second, on a finer scale, it is necessary to study genetic variation within species, both among geographically isolated populations and among individuals within single populations. Third, variation within the biological communities must be detected, as well the interactions among these three levels.

3.1. Species richness

The definition of a species has always been problematic. Indeed it is virtually meaningless for bacteria and other organisms that reproduce clonally and may exchange much genetic information across clones. For these, a "species" represents simply a largely arbitrary level of taxonomic aggregation. Even for sexual organisms, for which the diploid species may be defined fairly unequivocally, it must be recognized that species differ substantially in terms of how much genetic diversity they embody. Although the species is generally considered to be the fundamental unit for scientific analysis of biodiversity, it is important to recognize that biological diversity concerns the variety of living organisms at all levels: from genetic variants belonging to the same species; through arrays of species, families, and genera; and through population, community, habitat, and ecosystem levels. Biological diversity is, therefore, the "diversity of life" itself.

This issue underlines the difficulties involved in measuring biodiversity. A number of definitions has been developed as a means of comparing the overall diversities of different communities at different geographic scales. These definitions arise from the understanding that increasing levels of diversity lead to increasing levels of community stability, productivity, and resistance to invasion by non-indigenous species. The number of species in a single community is usually described as "species richness" or "alpha diversity", and can be used to compare the number of species in different geographical areas or biological communities. The term "beta diversity" refers to the degree to which species composition changes along an environmental or geographical gradient. For example, beta diversity is high if the species composition of communities changes on adjacent peaks of a mountain range, but is low if most of the same species occupy the whole mountain range. "Gamma diversity" applies to larger geographical scales; it refers to the number of species in a large region, or on a continent.

These three types of diversity are illustrated with reference to three mountain ranges in Figure 4.

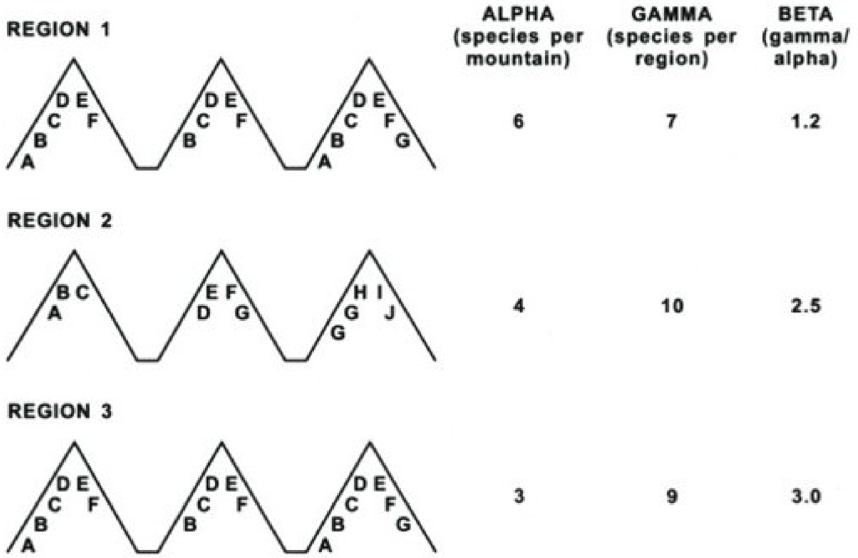

Figure 4. Biodiversity estimates of three regions, each with three mountains. Each letter refers to a population of a species. Alpha, beta, and gamma diversity are shown per each region. Region 1 has the highest alpha (i.e. local) diversity, that is the greatest average number of species per mountain; region 2 has the greatest total diversity, while region 3 has a more distinct assemblage of species than those in the other two regions (as shown by the higher beta diversity).

Region 1 has the highest alpha diversity, with a greater mean number of species per mountain (six) than the other two regions. Region 2 has the highest gamma diversity, with a total of ten species. Region 3 has higher beta diversity (3) than Region 2 (2.5) or Region 1 (1.2), because all of its species are found on one mountain each. A correlation is usually found between these three levels of diversity.

Spatial scale poses a difficult problem in the measurement of biodiversity. An ecosystem is often not well defined as a spatial unit and the measurement of diversity is very much conditioned by the scale of investigation. Numerous studies have characterized the relationship between the area surveyed and the number of species counted. The form of this relationship is a fundamental aspect of the description of diversity, capturing much more than simply the total number of species in the community (even if the boundaries of the community were known). Whatever controls this relationship controls biodiversity, but we are only beginning to understand the relative importance of factors such as fragmentation, isolation, migration, and mutation. A promising approach to such matters is the use of individual-based models, to help bridge the gap between our understanding of how individuals respond to varying conditions and the patterns observed on broad spatial scales.

3.2. Shortcuts to monitoring biodiversity: indicators, umbrellas, flagships, keystones, and functional groups

Because monitoring all aspects of biodiversity is difficult, a variety of shortcuts have been proposed whereby attention is focused on one or a few species. Five kinds of organisms and groups are identified as priorities, irrespective of their taxonomic status. These groups are:

- indicator species or groups
- umbrella species
- flagship species or groups
- keystone species
- functional groups.

Some *taxa* that are particularly sensitive to levels of disturbance, or to changes in the natural biota, can be used to monitor the health of an environment. However, the criteria for choosing such indicator species are very controversial, mainly because of confusion around the meaning of the term "health" in describing a system. For some researchers, species richness itself represents ecosystem health; for others, it is embodied in both structural diversity and aspects of function (like nutrient cycles), independent of species richness or composition. The *reductio ad absurdum* of these confused goals is the proposition that we should monitor virtually everything as indicators: a large group of species, dominance/diversity curves, canopy height diversity, percent cover, nutrient cycling, predation rates, and other factors. A more easily operative definition states that ecosystem health is denoted by: the absence of signs of ecosystem distress; an ecosystems ability to recover with speed and completeness (resilience); and/or a lack of risks or threats pressuring the ecosystem composition, structure, and/or function.

It is not obvious how to choose the best *taxa* useful to “indicate” ecosystem health. Usually, these species should be widely available, amenable to laboratory testing, easily maintained, and genetically stable. In freshwater communities, ideal features of resident species used as indicators to monitor aquatic pollution are as follows:

- Individuals should show a simple correlation between their pollutant content and the average environmental pollutant concentration, at all locations and under all conditions.
- Individuals should not be killed or rendered incapable of reproduction by the maximum level of the pollutant encountered.
- The species should be sedentary or have a restricted home range, so that findings relate directly to the environment in which it occurs.
- The species should be sufficiently large or abundant, to provide sufficient tissue for analysis.
- Individuals should be sufficiently widespread to facilitate comparative assessment in different areas.
- The species should be sufficiently long-lived to enable sampling of several year-classes and to provide information on long-term effects.
- Individuals should be easy to collect and identify, especially when they are to be used by people who are not expert in taxonomy.
- Individuals should be hardy enough to survive handling, if required.

Some criteria suggested for selecting indicator *taxa* for ecosystem health and attributes used to assess if *taxa* fulfil selection criteria are shown in Table 1. Table 2 provides a list of invertebrate indicator t*axa* reported by the primary biological literature published in English in the past 10 years.

SUGGESTED CRITERIA	ATTRIBUTES	VERTEBRATES %YES	VERTEBRATES %NO	INVERTEBRATES %YES	INVERTEBRATES %NO
BASELINE INFORMATION					
clear taxonomy	taxonomic status clear	100	0	97	3
biology and life history studied	>30 primary literature articles	56	44	75	25
tolerance levels known	tolerance levels studied	8	92	84	16
correlation to ecosystem changes established	correlation to ecosystem	1	99	3	97
LOCATIONAL INFORMATION	global distribution	54	46	69	31
cosmopolitan distribution	not migratory	38	62	100	0
limited mobility	home range size small	36	64	100	0
NICHE AND LIFE HISTORY CHARACTERISTICS	reproductive rate high	28	72	0	100
early warning and functional over range of stress	small body size	23	77	—	—
trends detectable	low or medium trophic level	64	36	82	16
low variability	low population fluctuactions	—	—	38	16
specialist	food/habitat specialist	15	85	100	0
easy to find and measure	easy to find	—	—	56	13
OTHERS	species at risk	30	70	19	81
taxa representing multiple agendas	economically valuable	18	82	3	93
multiple indicators used	multiple indicators suggested	9	91	0	100

Table 1. Suggested criteria for selecting indicator *taxa* of ecosystem health and attributes used to assess if *taxa* fulfil the criteria are in columns 1 and 2, respectively. Columns 3 and 4 include summary results of measured attributes for 100 suggested vertebrate and 32 suggested invertebrate *taxa*. Where percentage does not reach 100, not all *taxa* were categorised.

Suggested invertebrate taxa:

Oligochaeta: *Lumbricus terrestris*	Earthworms
Bivalvia: *Macoma balthica*	Clam
Amphipoda: *Pontoporeia hoyi*	Benthic arthropod
Araneae: *Erigone dentipalpis*	Spider
Araneae: *Oedothorax apicatus*	Spider
Araneae: *Pachygnata degeeri*	Spider
Araneae: *Xerolycosa miniata*	Spider
Araneae: *Pardosa pullata*	Spider
Homoptera: Membracidae, Cercopidae	Tree hoppers, froghoppers, spittlebugs

Coleoptera: Carabidae, Cicindelidae, Elateridae, Cerambycidae	Beetles
Diptera	Flies
Diptera: Chironomidae	Midges
Lepidoptera: Arctiidae	Tiger moths, footman moths
Lepidoptera: Nymphalinae	Brush-footed butterflies
Lepidoptera: Heliconiini, Ithomiinae	Heliconine and ithomiine butterflies
Lepidoptera: Morphinae, Satyrinae	Morpho butterflies, wood nymphs, satyrs
Lepidoptera: Papilionidae, Pieridae	Swallow tails, whites, orange-tips
Lepidoptera: Satyrinae: *Henotesia*	Satyrs, wood nymphs
Lepidoptera: Sphingidae, Saturnoidae	Hawk and silk moths
Hymenoptera: Formicidae,	Ants
Apoidea, Vespidae, Sphecidae	Bees, vespid and sphecid wasps
Hemip.: Coreidae, Pentatomidae, Cygaeidae, Tingidae, Myridae	True bugs
Collembola	Spring tails
Ephemeroptera: *Cinygmula*	Mayfly
Ephemeroptera: *Hexagenia limbata*	Burrowing mayfly
Isoptera	Termites
Odonata	Dragonflies, damsel flies
Plecoptera	Stoneflies
Trichoptera	Caddisflies

Table 2. List of invertebrate indicator *taxa* reviewed.

The major shortcomings of the invertebrate species reviewed include failures to establish correlation between changes in the indicator *taxa* and selecting *taxa* at high taxonomic level, which potentially increases the number of inappropriate species and "noise" in the data. Further research is needed to establish a clear understanding of what indicator *taxa* can actually be expected to indicate and to formulate objective measurement units of ecosystem health that can be correlated with indicator *taxa*.

There are five major contexts in which these species may serve to indicate pollution in various ways. The species may be classified as follows:

- *Sentinels:* species introduced to an environment as "early warning devices" or to determine the effect of a pollutant.
- *Detectors:* species occurring naturally in an area and which show a measurable response to environmental changes.
- *Exploiters:* species whose presence indicates disturbance or pollution.
- *Accumulators:* organisms that take up chemicals from their environment in measurable quantities and accumulate them in their bodies.
- *Bioassay organisms:* those used in laboratory tests to detect pollutants, or to rank levels of toxicity.

"Umbrella species" are species characteristic of a particular community or habitat whose safety can assure (or help assure) that of many less conspicuous, or less well-known, *taxa* in the places where they live. For example, velvet worms (Onychophora) in humid forest habitats (such as rotting logs), in parts of the tropics and southern temperate regions and in caves, are among the most notable and conspicuous members of the specialized communities that depend on those habitats. Their presence is sufficient to demonstrate the presence of an unusual community: protection of habitats or sites characterized by the presence of Onychophora can protect a multitude of other *taxa* living in wet forest litter, or in caves, by reducing the incidence of threats to their environments.

"Flagship *taxa*" are "charismatic" species, whose appeal to humans serves to increase awareness of conservation needs by helping gain public and political sympathy. They often embody the following features, which may be used in their promotion:

- Taxonomy must be well known, with most species easy to recognize without a need to capture them.
- Species must be able to engender public sympathy for their well-being, on the basis of aesthetic value, commodity value, or both.
- The group must be relatively diverse and widespread, but should include localized or narrowly endemic *taxa* which can be used to monitor local community health and to foster local "pride" or goodwill as part of broad conservation awareness.
- They should frequent an array of different habitats and contain specialized species which respond to habitat changes.

Many flagship species are, in essence, "emblems" for local or national conservation efforts. They can have important direct benefits to other *taxa*, as well as less tangible benefits to their natural communities. The Florida Panther, *Felis concolor coryi*, is the quintessential flagship species: it is so charismatic that thousands of Floridians willingly pay US$66 annually to have an automobile license plate with its picture. These funds go towards conservation, as do others generated in private appeals featuring the panther. The attempt to preserve the panther, at both state and federal levels, has been enormously expensive, costing around US$1.4 million. These costs have included establishing a journal (*Coryi*) devoted solely to this animal, extensive field management projects, and field and laboratory studies.

The concept of "keystone species" (or "critical species") suggests that, at least in many ecosystems, some species affect the organization of a community to a far greater extent than might be predicted from consideration of their biomass or abundance. The removal of a keystone species leads to qualitative shifts in ecosystem properties and determines the integrity of the community and its unaltered persistence through time. Top predators, such as wolves, are among the most obvious keystone species, because they are often important in controlling herbivore populations. Without wolves, populations of deer and other herbivores often increase, leading to overgrazing, loss of plant cover, loss of associated insect species, and soil erosion. An excellent example of an invertebrate keystone species is "krill" in Antarctic Ocean waters. Krill are a group of euphausid crustaceans, the most predominant of which is *Euphausia superba* occuring in a circumpolar band around Antarctica. They feed mainly on diatoms and are an important food source for vertebrates, especially penguins, seals, and whales. They play a major role in converting plant to animal biomass and constitute about half the standing crop of zooplankton.

The definition of "keystone" has seen expansion; species which are not near the top of foodwebs may also now be so defined. For example, "keystone mutualists" are plant species that support many animal species, whose activities may support many other species in turn. Species may also serve as keystones because they change the physical structure of their environment. The beavers *Castor canadensis*, with their dams, provide shelter for numerous other species; in the longleaf pine forest, the burrows of the gopher tortoise *Gopherus polyphemus* are home to 332 other species. The expansion of the keystone species concept has led some researchers to criticize it as so “fuzzy” that it is impossible to say what a keystone species is and what is not. It seems more reasonable to refine it than to discard it, however. A recent research effort aimed to quantify the criteria for keystone species designation and attempted to separate the concept from that of an "ecological dominant": a species whose great biomass and abundance make it crucial for an entire community, often constituting its base structure. The research on keystone species could provide knowledge about the functioning of the target ecosystem and insights into how to make conservation efficient. It would force researchers to consider species directly, rather than only the processes that might or might not maintain them.

The notion of a functional group is very attractive. From the viewpoint of system theory, large ensembles of interacting components are expected to self-organize into clusters that interact more strongly among themselves than with other such clusters. Such hierarchical organization is characteristic of ecosystems. Functional group approaches to vegetation are based on properties such as life-form and phytosociological association and rely on the interplay between evolution and plant adaptive strategies as an organizing principle. Even when the roles of species within groupings cannot be distinguished, diversity and redundancy within groupings are critical features of a systems ability to respond to change and disturbance. Thus, this concept provided one of the most compelling arguments for the maintenance of biodiversity: in the short term, elimination of redundancy within groups may lead to no noticeable change in system dynamics. Over time, systems with reduced within group diversity will be less able to respond to changes and more likely to collapse.

-
-
-

Bibliography

Caughley, G. 1994. Directions in Conservation Biology. *Journal of Animal Ecology*, No. 63, pp. 215-244. [A critical discussion of the two threads of conservation biology: the small-population paradigm and the declining-population paradigm, both requiring some amelioration of their conceptual and operative frameworks.]

Caughley, G.; Gunn, A. 1996. *Conservation Biology in Theory and Practice*. Cambridge, Mass., Blackwell. 459 pp. [One of the clearest and most complete manual on the conservation biology.]

Diamond, J. M. 1984. "Normal" Extinction of Isolated Populations. In: M. H. Nitecki (ed.) *Extinctions*, pp. 191246. Chicago University Press. [The contribution which first introduced the "Evil Quartet" concept and thus opened the discussion on the causes underlying the recent threats to biodiversity.]

Diamond, J. M. 1989. Overview of Recent Extinctions. In: D. Western; M. Pearl (eds.). *Conservation for the Twenty-First Century*, pp. 3742. New York/Oxford, Oxford University Press.

Dynesius, M.; Nillson, C. 1994. Fragmentation and Flow Regulation of River Systems in the Northern Third of the World. *Science*, No. 266, pp. 753-762.

Edwards, P. J.; Abivardi, C. 1998. The Value of Biodiversity: Where Ecology and Economy Blend. *Biological Conservation*, No. 83, pp. 239-246. [The article discusses how much humans depend upon wildlife for a wide range of so-called ecosystem services. Authors underline concepts and theories of ecological economics as an emerging discipline.]

Eldredge, N. 1992. *Systematics, Ecology, and the Biodiversity Crisis*. New York, Columbia University Press. 220 pp. [The most thorough manual explaining the necessary links among systematics, ecology, and biodiversity conservation.]

Elton, C. S. 1958. *The Ecology of Invasion by Animals and Plants*. London, Methuen. 181 pp. [The historical basis of the science of biological invasions, written by the father of animal ecology in Britain. The book is aimed at a lay audience.]

Enserink, M. 1999. Biological Invaders Sweep In. *Science*, No. 285, pp. 1834-1836. [A synthetic article clearly explaining the phenomenon of invasions, attempts by ecologists to arrest the process, and the difficulties encountered in forecasting new potentially invasive species.]

Harwood, J. 2000. Risk Assessment and Decision Analysis in Conservation. *Biological Conservation*, No. 95, pp. 219-226. [As a response to the fundamental problems conservation biologists face when they provide advice to managers, the author analyses some uses of computer-intensive techniques to develop a methodology of risk assessment combined with decision analysis.]

IUCN (International Union for the Conservation of Nature and Natural Resources). 1990. *The red data book of endangered animals*. Gland, Switzerland. IUCN.

IUCN (International Union for the Conservation of Nature and Natural Resources). 1994. *IUCN Red List Categories*. Gland, Switzerland, IUCN.

IUCN (International Union for the Conservation of Nature and Natural Resources). 1996. *IUCN Red List of Threatened Animals*. Gland, Switzerland, IUCN.

Laurance, W. F. 1999. Reflections on the Tropical Deforestation Crisis. *Biological Conservation*, No. 91, pp. 109-117. [Facing the tropical deforestation crisis, the author highlights the benefits to be derived from tropical forests, and assesses the pattern and pace of tropical forest destruction in America, Asia, and Africa.]

Lodge, D. M. 1993. Biological Invasions: Lessons for Ecology. *Trends in Ecology and Evolution*, No. 8, pp. 133-137. [An accurate analysis of the ecological consequences of species introductions, often leading to the homogenization of ecosystems.]

Lvei, G. L. 1997. Global Change through Invasion. *Nature*, No. 388, pp. 62-78. [A careful analysis of the changes induced by the invasion of non-indigenous species.]

Maitland, P. S. 1995. The Conservation of Freshwater Fish: Past and Present Experience. *Biological Conservation*, No. 72, pp. 259-270. [This article explains some of the reasons why various fish species have been lost, and why there are now thousands of lakes and rivers which are fishless or possess only degraded communities. The need for major fish conservation programs is stressed.]

Miller, K. R. 1980. *Planning National Parks for Eco-development*. Ann Arbor, Michigan, University of Michigan Press. [A thorough examination of the programs that have to be followed while planning national parks and reserves and a careful analysis of their roles within the optics of an eco-sustainable development.]

Myers, J. H.; Simberloff, D.; Kuris, A. M.; Carey, J. R. 2000. Eradication Revisited: Dealing with Exotic Species. *TREE*, No. 15, pp. 31620. [The problem of eradication is here carefully analyzed, and the balance between the pros and cons of various eradication procedures considered.]

New, T. R. 1995. *An Introduction to Invertebrate Conservation Biology*. Oxford, New York, Melbourne, Oxford University Press. 194 pp. [This is the first book to give a global view of the conservation biology of invertebrates in their major habitats. Discussion of the importance of invertebrates and the rationale for their conservation, and of priorities in the field, is followed by an appraisal of threatening processes, and practical approaches to invertebrate conservation.]

Primack, R. B. 2000. *A Primer of Conservation Biology*. Sunderland, Mass., Sinauer. 280 pp. [This book provides a brief but thorough introduction to the major concepts and problems of conservation biology. It is intended for use in short courses in conservation biology, and can also be used as a supplemental text for general biology, ecology, wildlife biology, and environmental policy courses. It is also a concise guide for professionals who require a background in the subject.]

Rejmnek, M. 2000. Invasive Plants: Approaches and Predictions. *Austral Ecology*, No. 25, pp. 497-506. [A synthetic review of the invasiveness of plants, stressing the need for correct approaches and soundly-based predictions.]

Simberloff, D. 1998. Flagships, Umbrellas, and Keystones: Is Single-Species Management Pass in the Landscape Era? *Biological Conservation*, No. 83, pp. 247-257. [Proposed "short cuts" involving monitoring and/or protection of single species are critically discussed. In particular, the author attempts a definition of the "keystone species" concept, while admitting the risks of viewing it as a panacea.]

Simoncini, R., Milward, S., Terry, A. (eds.) 2004. How to Develop Effective Local Agri-Environmental Measures. Introductory Guidelines for Rural Development Planners and Administrators. IUCN website, publications, http://www.iucn.org/places/europe/rofe/rofe_publications/publications.htm, under Biodiversity and Agriculture. [The first guidelines for an environmentally sustainable agriculture in Europe.]

Soule', M. (ed.) 1986. *Conservation Biology: The Science of Scarcity and Diversity*. Sunderland, Mass., Sinauer. 584 pp. [A synthesis of the scientific foundation for the protection and management of biological diversity. Its comprehensive bibliography and suggested reading lists help make this book accessible to the student and professional alike.]

Soule', M. E.; Wilcox, B. A. 1980. *Conservation Biology: An Evolutionary-Ecological Approach*. Sunderland, Mass., Sinauer Associates.

Storfer, A. 1999. Gene Flow and Endangered Species Translocations: A Topic Revisited. *Biological Conservation*, No. 87, pp. 173-180. [An article crucial to understanding the pivotal role of gene flow to the conservation of endangered populations.]

Tansley, A. G. 1935. The Use and Abuse of Vegetational Concepts and Terms. *Ecology*, No. 16, pp. 284-307.

Van Dyke, F. 2003. Conservation Biology. Foundations, Concepts, Applications. Boston/Toronto, McGraw Hill, pp. 413. [A complete and updated manual of conservation biology.]

Van Driesche, J.; Van Driesche, R. 2001. Guilty until Proven Innocent. *Conservation Biology in Practice*, No. 2, pp. 8-17. [An article that clearly outlines some rules to follow in order to prevent accidental introductions of pests.]

Western, D.; Pearl, M. (eds.) 1989. *Conservation for the Twenty-First Century*. New York/Oxford, Oxford University Press. 365 pp. [A challenging and thought-provoking book: an essential addition to environmental science, conservation, wildlife, and ecological collections.]

Western, D.; Pearl, M. C.; Pimm, S. L.; Walker, B.; Atkinson, I.; Woodruff, D. S. 1989. An Agenda for Conservation Action. In: D. Western, M.; Pearl, (eds.) *Conservation for the Twenty-first Century*. New York/Oxford, Oxford University Press. 365 pp.

Williamson, M. 1996. *Biological Invasions*. London, Chapman and Hall. [The seminal publication in the science of biological invasion. Anyone wishing to understand the problem of invasive species, from ordinary citizens through to specialist researchers, can profit from reading this book.]

Wilson, E. O. 1984. *Biophilia*. Cambridge, Mass., Harvard University Press. [A new approach to viewing and understanding biodiversity in its social, ethical, and aesthetic roles.]

Wilson, E. O. 1989. *Conservation: The Next Hundred Years*. In: D. Western, M.; Pearl, (eds.). *Conservation for the Twenty-First Century*, pp. 37. New York/Oxford, Oxford University Press.

Wilson, E. O. 1992. *The Diversity of Life*. Cambridge, Mass., Harvard University Press. [One of the most complete manuals dealing with biodiversity.]

Biographical Sketches

Dr Francesca Gherardi teaches Zoology, Conservation Biology, and Applied Ethology at the University of Florence (Italy). She received her Ph.D. in Animal Biology in 1987 and is currently a permanent researcher at the Department of Animal Biology and Genetics "Leo Pardi". Dr Gherardi is actively involved as a referee for more than 30 international journals. She is associate editor of the *Journal of Crustacean Biology* (USA), *Ethology, Ecology, and Evolution* (Italy), and *Biological Invasions* (The Netherlands). She has been also editor of *Crayfish in Europe as Alien Species. How to Make the Best of a Bad Situation?* (A. A. Balkema, Rotterdam, 1999) and of *Biological Invasions in Inland Waters* (Springer, The Netherlands, 2007). Dr Gherardi has coordinated six international workshops and held more than 100 presentations at international and national meetings and conventions. She directed or participated to scientific expeditions abroad, in particular in: East Africa (Somalia and Kenya), South Africa, Indian Ocean, Israel, USA, Western Australia, and Europe. In Italy, she worked at the Stazione Zoologica "A. Dohrn" in Naples. She has been the President of the International Association of Astacology (2004-2006) and a member of five other societies, including the American Association for the Advancement of Science and the Crustacean Society. She worked as Summer Fellow at the MBL at Woods Hole in 2003-04 and as Visiting Scholar at the Columbia University in the City of New York in 2006 and 2007. Dr Gherardi is the author or co-author of more than 140 scientific articles published in peer reviewed international journals, more than half devoted to problems of biodiversity conservation; she is also the author of eight reports commissioned by public administrations. She has participated in six EU projects, and in projects funded by NATO and by the Australian Nature Heritage. Dr Gherardi is currently a partner of the EU project "Environmental impacts of invasive alien species in aquaculture (IMPASSE)" and acts as supervisor for projects funded by the Ministry of University, the Ministry of Agriculture, and local administrations.

Claudia Corti received her degree in Biological Sciences at the University of Florence (Italy). Since 1981, she has been working at the same University in the Herpetological collection of the Zoological

Section of the Museum of Natural History and then in the Department of Animal Biology and Genetics. She has been the managing editor of *Ethology Ecology Evolution* (Italy), coordinated international meetings, and held several presentations at meetings and conventions. She took part to many scientific expeditions abroad, mainly focused on the Mediterranean and Caucasus. In Italy, she collaborates with several institutions, including protected areas and parks. Dr. Corti is author of many publications and acts as a referee for different international journals. Since 1991, she has been a lecturer of Comparative Anatomy and of Experimental Biology. She is one of the coordinators of the Atlas of Amphibians and Reptiles of Italy (for Sardinia) published by the Societas Herpetologica Italica, and member of: the Council of the Societas Europaea Herpetologica, the scientific committee of Mediterranean Lacertidae, and the Societas Herpetologica Italica. Her main scientific interests include studies on the distribution of amphibians and reptiles in the Mediterranean, with a particular emphasis on islands and on the relationships between biodiversity conservation and agriculture. Recently, Dr. Corti has been elected as Honorary Fellow of the California Academy of Sciences, U.S.A.

Manuela Gualtieri is an associate professor at the Department of Zootechnical Sciences of the University of Florence, and lecturer in Microlivestock Breeding and Aquaculture. She is a member of five national and international associations, including the European Aquaculture Society, and is carrying out researchers into animal nutrition and aquaculture, with particular emphasis on the growth and quality of fish. She is author of one book and of around 70 articles.