Cambridge University Press
978-0-521-82763-8 - Zoo Conservation Biology
John E. Fa, Stephan M. Funk and Donnamarie O'Connell
Excerpt
More information

1 · *Biodiversity and zoo conservation biology*

'It may well be true that Sumatran tigers and Hyacinthine macaws seem to contribute very little to our daily lives. There is, though, a strong group of arguments . . . which say that wild animals and plants can be good for us and this is a good reason to hang on to them' (Colin Tudge)

1.1 Introduction

In practical terms, species conservation initiatives must be directed at protecting the largest number of forms as cheaply as possible. Economy, not just in monetary terms but also in achieving parsimonious ways of protecting species, is important, since resources are often limited. Debates rage over whether one or another approach is more appropriate, often with much time and effort expended and little results in hand. Biodiversity conservation has to proceed along various fronts achieved by the integration of methods to halt the current extinction of species. This book attempts to undertake this task for conservation biologists working in zoos. Zoos argue that their role is increasingly concerned with the preservation of species yet the information required for zoo staff to make informed decisions on any aspect of captive animal care, population management, etc., is not readily accessible.

This book collates and evaluates numerous papers and books published on the subject to produce a theoretical and practical document that understands the reality of keeping animals in captivity and the potential that these institutions have in biodiversity conservation. The need for such a textbook is further emphasised by the fact that although there has been a certain growth in literature that deals with the application of science to techniques for the optimal maintenance and breeding of animals in captivity, there is no text that examines the fundamental concepts underlying captive animal management. Therefore, this is not a book on the techniques of managing animals in captive collections, but one that takes a more 'aerial view' of the subject of how zoos do and can contribute further to species conservation. This book covers some subject matter that has to do with the 'biology of the management of animals in captivity', as Hediger (1950) put it (Chapter 3), but its main purpose is to review (both numerically and qualitatively) what zoos are, what they are doing and what they can do as healthy educational and research establishments.

In this first chapter, we present information on the world's biological diversity in order to place zoos firmly within this framework. Understanding what is meant by biodiversity, where it is found and how it is being lost, is crucial to clarify what needs to be done to conserve species and habitats worldwide. Here, we summarise these main issues first, starting with what we mean when we talk of a species. We then examine what factors make species rare, and what we know about past and present rates of species extinctions. We then examine why it is important to value conserving biodiversity. Finally, we set the context of the book by characterising what we are calling zoo conservation biology – or how zoos can truly engage in the conservation of biodiversity.

1.2 Species definitions

In biology in general, a species is the smallest basic taxonomic unit used to define living organisms (Box 1.1). Traditionally, a species has been defined in one of two ways, as a group of individuals that is morphologically, physiologically, or biochemically distinct from other groups (the **morphological species** concept) or as a group of individuals that can potentially breed among themselves and do not breed with individuals of other groups (the **biological species** concept).

Understanding how to differentiate geographic patterns of biological variation is critical for conservation, because of its essential role in delimiting discrete taxonomic units in nature (Ryder, 1986; Barrowclough & Flesness, 1996). Decisions about allocating space for captive breeding in zoos, or breeding programmes for maximising genetic diversity, depend on being able to distinguish correctly the different taxonomic forms. How we view the species concept therefore has consequences on how we perceive patterns of diversity and endemism, how variation is apportioned between and among groups, and in some cases how population sizes of various taxonomic entities might be determined. This is not easy and debates over what is a species are long-standing (see Davis, 1996). Mallet (2007) discussed a few of the major alternative concepts and definitions in terms of the most important practical effect of species concepts in taxonomy. More detailed discussions and critiques of various species concepts can be found in Mallet (2001) and Coyne & Orr (2004).

Box 1.1 • *Naming species and the 'taxonomic impediment' question*

Scientific species names essentially consist of two words. This system, known as binomial nomenclature, was developed in the eighteenth century by the Swedish biologist, Carl von Linnaeus. In the scientific name for the tiger *Panthera tigris*, *Panthera* is the generic or genus name and *tigris* is the specific epithet often referred to as the species. The genus name can be compared to a person's family name in that many people can have the same family name, while the species name is similar to a person's given name. *Panthera tigris* refers to just one of the four species of big cats. Scientific names are written in a standard way to avoid confusion. Sometimes scientific names are followed by the authority's name, as in *Panthera tigris* Linnaeus 1758 indicating that Linnaeus was the person who first proposed the scientific name and published it in 1758. Most scientific names have Latin or Greek roots; *Panthera* is Latin, from the Greek word for leopard.

Tiger subspecies represent an interesting example of how systematics can assist conservation. No comprehensive modern analysis of geographic variation had been undertaken until Cracraft *et al.* (1998) studied the various forms. Using DNA sequencing techniques,

Cambridge University Press
978-0-521-82763-8 - Zoo Conservation Biology
John E. Fa, Stephan M. Funk and Donnamarie O'Connell
Excerpt
More information

Cracraft *et al.* (1998) considered the Sumatran Tiger to have a sufficiently distinct mitochondrial DNA to warrant species status. Mazák & Groves (2006) also considered the Sumatran tiger a separate species on the basis of morphology, as well as the Javan Tiger. But also based on body characteristics, however, Kitchener (1999) considered that there is little evidence for discrete subspecies and morphological variation was best characterised as clinal. Luo *et al.* (2004) later confirmed the division of tigers into six extant subspecies on the basis of distinctive molecular markers.

Biodiversity science has emerged as one of the frontier areas of research with expanding concepts, testable hypotheses and ever-refining methodologies. Being a synthetic discipline, it is primarily 'fed' by the established fields of biological sciences, such as taxonomy, biogeography, ecology, evolution, genetics, and the like. Taxonomy, which essentially deals with discovery, description and classification of living organisms, underpins the basic understanding of biodiversity on Earth (McNeely, 2002). The identification of organisms within communities to species level is one of the greatest constraints in terms of time and costs in ecological studies. Though some studies have suggested that working at a taxonomic level higher than species does not result in an important loss of information (taxonomic sufficiency) it does, however, lead to an inaccuracy of biodiversity evaluation. This is especially important when comparing different areas, and can lead to an *a priori* exclusion of some entities before understanding their role in ecology.

Some authors argue that taxonomy has been considered a marginal science even during the pioneer descriptive period of ecology, and traditionally has received little financial support, that there is a taxonomic impediment (Giangrande, 2003). The result was the production of many misidentifications and erroneous records. During recent years, the developing experimental ecological approach has led to an improvement in scientific methods, but concurrently to a reduction in the number of expert taxonomists for many invertebrate groups. Such a worldwide shortage of taxonomists, who can be called upon to identify species, describe those that are new to science, determine their taxonomic relationships, and make predictions about their properties (Gaston & May, 1992), is concerning and is expected to worsen. This is because the taxonomic workforce is aging, coupled with a decline in students being trained in taxonomy. To complete the picture, there is a decline in the number of paid positions that allow a person to spend time doing basic taxonomy. What is NOT lacking is an interest in taxonomy by potential taxonomists. The argument is often made that even the existing number of trained taxonomists are under-utilised due to insufficient commitment of funds to taxonomic study. Every major museum suffers from a backlog of unstudied specimens and undescribed new species, while curators often cite the loss of students who were interested in taxonomy, but could not get sufficient fellowship support or failed to find a paying job.

The decline in taxonomists available to study biodiversity seems puzzling since in the 1990s there was a promotion of inventory, use, and protection of biodiversity as never before. The recognition then was that taxonomic information is a prerequisite to understanding biodiversity and maximising its use and protection. It is also widely accepted that, outside mammals, birds, and some plant groups, we know only a fraction of the species on earth. The groups that are the least-known are those with the most potential for discovery of products of use to humankind, and for understanding emerging diseases and agricultural pests.

However, since the advent of molecular techniques, the species debate has become even more complicated because phylogeneticists have their own opinions on how a species should be defined. Thus, little consensus on species concepts has yet been reached. Some argue that named Linnean ranks, including species, are no longer useful in taxonomy at all (Mishler, 1999; Hendry *et al.*, 2000a). However, attempts at consensus have been made. Poulton (1904), Simpson (1951) as well as Templeton (1989) have argued that a combination of morphological, ecological, phylogenetic, and reproductive criteria should be used. Sokal & Crovello (1970) and Mallet (1995) attempted the reverse argument: that one could arbitrate between conflicting 'concept' arguments by using the results of clustering processes on phenotype or genotype, rather than by specifying the processes themselves. Some authors, like de Queiroz (1998), have argued that conflict between species concepts is illusory, because different concepts represent criteria applicable to different stages in the lineage-splitting process. However, this attempt at consensus does not help with the practical question of whether to use inclusive or diagnostic criteria in taxonomy; that is, whether to be a lumper or a splitter. It seems likely, therefore, that species concepts and criteria will continue to be debated for some time. Until a practical solution is widely agreed, nomenclatural databases for comparative biology and biodiversity are essential. On a more practical basis, conservation that can continue to provide useful information, while fashions in the taxonomic rank considered species fluctuate, is required. Because of uncertainty of the species rank (Hey, 2001) and because the term '*species*' can mean different things in different taxonomic groups; species counts on different continents or of different organisms will give only a roughly comparable idea of biodiversity. Isaac *et al.* (2004) were watchful of the problem that 'taxonomic inflation' can cause when assessing whether rates or risks of extinction have changed over time. This is so because much conservation planning depends on numbers of species, reflecting richness, diversity, endemism, threat and many other attributes that can be compared across locations and taxa. Hence, species numbers will increase (because more are recognised), potentially masking extinction, but taxonomic inflation will also result in a higher proportion of threatened or extinct species, because the average geographical range and population size will decline (Agapow *et al.*, 2004). Isaac *et al.* (2004) suggest that these effects will make global targets very hard to meet.

In conservation studies such as those discussed in this book, we are generally concerned about the underlying mechanisms that can allow managers to make prudent decisions. Thus, the importance of what we call a species cannot be underestimated because the issue becomes one of what are we to protect or manage if we do not know how to recognise it? Despite the fact that many biologists' attitude toward the debate is one often bordering on complacency, species concepts have consequences for determining units for captive breeding and management, specifying units to be protected under law, or regulating trade in endangered taxa (Cracraft *et al.*, 1998). The main controversy within conservation seems to be between those who prefer to view the problem of units-in-nature from a position of formal taxonomy and those who wish to avoid formal taxonomy altogether and apply another set of terms considered to be relevant to conservation action. Among the latter are ESUs, 'management units' and other such expressions. ESUs are difficult to recognise and according to Cracraft (1997) they have no status within taxonomy, because the concept is not backed-up by centuries-old scholarship, tradition or widely accepted rules of procedure. In any case, ESUs are not dissimilar to several other formal species concepts, particularly the phylogenetic species concept. The ESU concept has gained support because the biological species concept could not provide a consistent terminological solution to the units-in-nature problem (Ryder, 1986). Biological species are problematic to use as a unit of conservation because too many biological species contain multiple, differentiated, and often geographically isolated taxa. Subspecies, moreover, are not easily used because although some are distinct, geographically localised units, others are arbitrary subdivisions of continuously distributed geographic variation and are not distinct units. Because of this, some taxonomists have supported the notion that some form of phylogenetic species concept is more appropriate for conservation (Cracraft, 1997). Phylogenetic species are diagnosably distinct taxa; one or more populations that share a combination of characters that distinguish them from other units (Sites & Crandall, 1997).

1.3 What is biological diversity?

Biological diversity means the wealth of life forms found on earth: millions of different plants, animals and microorganisms, the genes they contain and the intricate systems they form. However, life on earth contains much greater variety than that measured by species alone. A single species may contain different races or breeds and differences may also exist at the individual level. Species come together to form communities which, in turn, combine in ecosystems. Many species survive in only one specific ecosystem and thus discussions involving biological diversity must define the concept at least at three distinct levels: genetic, species and ecosystem diversity. Human cultural diversity could also be considered part of biodiversity since human cultures represent 'solutions' to the problems of survival in particular environments.

Genetic diversity. Genes are the biochemical information packages passed on by parents to determine the physical and biochemical characteristics of the offspring. Genetic diversity can refer to the variation found in genes within species. Although most of the genes are the same, subtle variations occur in some. The expression of these variations may be obvious, such as size and colour; they may also be invisible, for example, susceptibility to disease. Genetic variability allows species to adapt to changes in their environment and can be manipulated to produce new breeds of crop plants and domestic animals.

Species diversity. Species are usually recognisably different in appearance, allowing an observer to distinguish one from another, but sometimes the differences are extremely subtle. Species diversity, or **species richness** (McIntosh, 1967), usually measures the total number of species found within one geographical area. The problem in measuring species diversity is that it is often impossible to enumerate all species in a region.

Ecosystem diversity. An **ecosystem** consists of communities of plants and animals and the non-living elements of their environment (soil, water, minerals, air, etc.). The functional relationships between the communities and their environment are frequently

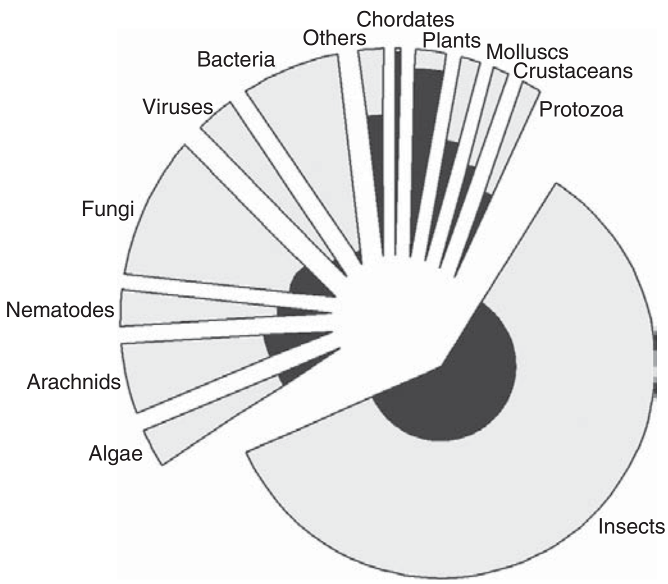

Fig. 1.1 Species richness in major groups of organisms. The main 'pie' shows the species estimated to exist in each group; the black area within each slice shows the proportion that has been formally described. From Purvis & Hector (2000), data from Hawksworth & Kalin-Arroyo, 1995).

complex, through the mechanisms of major ecological processes such as the water cycle, soil formation, nutrient cycling and energy flow. These processes provide the sustenance required by living communities and so lead to a critical interdependence. Two different phenomena are frequently referred to under the heading of ecosystem diversity: the variety of species within different ecosystems (the more diverse ecosystems contain more species) and the variety of ecosystems found within a certain biogeographical or political boundary.

1.4 How many species are there?

It is difficult to quantify the world's genetic diversity. Estimates have varied from 2 million to 100 million species, with the most common estimate of somewhere near 10 million. Diversity at the species level is somewhat better known, but current estimates of the number of species only serve to underscore our degree of ignorance. The problem defining the limits of current knowledge of species diversity is compounded by the lack of a central database or list of the world's species. A recent compilation (Wilson, 1988) has shown that since the beginnings of the science of taxonomy, scientists have identified and named about 1.4 million species of living organisms (Fig. 1.1). Of the described forms around 1.03 million are animals and 248 000 are higher plants. The best studied and most completely known groups are birds and mammals (roughly 9000 and 4000 species respectively) although together they account for less than 1% of all known species. About 80% or more of all species of birds, mammals, reptiles, amphibians and fishes have been described. Insects, however, are still little known despite the fact that they account for a high proportion of all known species. The number of insect species was estimated by C. B. Williams in 1969 to be around 3 million. By 1988, Stork (1988) estimated that insects comprised 57% of the total named species and one group of insects, the beetles, comprised 25%. Using knockdown insecticides, Erwin (1982) astonished the ecological world with his estimate of how many insects live in tropical forests. Working in Barro Colorado Island, Panama, Erwin sampled 19 individual *Luehea* trees (Family Tiliaceae) at different seasons. He collected 9000 beetles belonging to more than 1200 species. Erwin extrapolated from these data to estimate that 13.5% of these beetles (about 162 species) live only in Luehea trees. He then deduced that since roughly 50 000 species of tree live in tropical rainforests around the world and 'guácimo colorado' represents an average tropical tree, there must be about 1.8 million beetle species specialising on single tree species. Because some beetles live on more than one tree species (Erwin thought about 2.7 million of them) a total of 10.8 million species of canopy beetles was possible. If all these estimates are correct, as many as 30 million species of insects are possible. Each step in Erwin's calculation of species diversity is so speculative that many scientists do not accept this estimate and keep to the earlier figure of 10 million total species (Gaston, 1991). Two other approaches have been employed in estimating biological diversity. The first, **biological rules**, involves determining how many species are involved in biological relationships. May (1988, 1992) estimated that in Britain and Europe there are about six times more fungi than plant species. Thus, if this ratio applies throughout the world there may be as many as 1.6 million fungus species growing on the world's 270 000 plant species. A second method, of associated specialists, assumes that if each species of plant and insect has at least one species of specialised bacteria, protist, nematode and virus, estimates of the number of species should be multiplied by five – a grand total of 25 million using traditional estimates, or 150 million if Erwin's estimates are accepted.

New species are still being discovered – even new birds and mammals. On average, about three new species of birds are found each year. Although many assume nearly all mammal species are known to scientists, since 1993, 408 new mammalian species have been described, around 10% of the previously known fauna (Ceballos & Ehrlich, 2009). Other vertebrate groups are far from being completely described: an estimated 40% of freshwater fishes in South America have not yet been classified. Additionally, environments such as soil and the deep sea are revealing an unsuspected wealth of new species. Scientists believe that the deep sea floor may contain as many as a million undescribed species (Grassle, 1989). Hydrothermal vent communities discovered less than two decades ago contain more than 20 new families and subfamilies, some 50 genera and 100 new species.

1.5 Where is biological diversity found?

Biological diversity occurs within all habitats, because genetic diversity has allowed life to adapt to different environments. However, species are not spread evenly over the earth and biological diversity is greater in some areas than in others. Some habitats, particularly tropical forests among terrestrial systems, possess a greater number or density of species than others. For example, a 13.7 km^2 area of the La Selva Forest Reserve in Costa Rica contains almost 1500 plant species, more than the total found in the 243 500 km^2 of Great Britain, while Ecuador harbours more than 1300 bird species, or almost twice as many as the USA and Canada combined (Myers, 1988). Global biodiversity generally follows four clear patterns: (1) species diversity increases towards the tropics for most groups of organisms; (2) patterns of diversity in terrestrial species are paralleled by patterns in marine species; (3) species diversity is affected by local variation in topography, climate and environment; and (4) historical factors are also important.

In general, the number of species (more cautiously called inventory of species by Rosenweig, 1997) declines as you move away from the equator, north or south. Examples of these latitudinal gradients, as the effect is known, abound. Since first described by Alfred Russell Wallace in 1878, around 14 different hypotheses have been proposed to explain this phenomenon (Pagel *et al.*, 1991). It has been found in plants and animals in both aquatic as well as terrestrial environments. There are exceptions, such as marine algae in the North/Central American Pacific (Gaines & Lubchenco, 1982), but these are indeed departures from the general pattern. Latitudinal gradients in species richness have also been found for fossil forms, in the Foraminifera for data stretching for 70 Myr and in flowering plants in a data set of around 110 Myr.

Concerns were raised about whether increasing species diversity along the tropics was an artefact of disproportionate interest by temperate area scientists describing the patterns in tropical areas. This worry was dispelled by comparing similar species in studied communities. For instance, one hectare (1 ha) of Atlantic rainforest in Bahia Province, the richest in the world, has 450 tree species (Thomas & de Carvalho, 1993). In other more typical tropical forests, one hectare can have around 200–300 tree species. A test of latitudinal gradient in species richness comes from a study by Terborgh *et al.* (1990) which meticulously compared the avifauna of a 97 ha tropical forest in Peru with a similar-sized area in the temperate region of North America. They believed that even though gamma diversities (the number of species in a region) have been shown to differ considerably between tropical and other areas, others like MacArthur (1965) conjectured that the alpha diversity (the diversity of species in a particular geographical point) could be the same. The results showed that whilst in the tropical forest there were 160 bird species, the richest temperate forest had four to five times faver species. Such wealth occurs although the number of individual birds per hectare is quite similar in the two biomes.

A corollary to the observed increases in species richness towards the equator is the latitudinal gradient in geographic range size, or Rapoport's rule (Stevens, 1989). Rapoport's rule has been demonstrated for a large variety of different taxa, although some exceptions have been found. The rule essentially describes how species' ranges at the polar end of a continent are larger than those at the equatorial end. An explanation for Rapoport's rule for mammals is that an individual animal at the polar end of a continent experiences a much wider range of climatic conditions than one at the equator. Thus unlike tropical species, the more temperate species cannot specialise on a narrow set of climatic conditions. In addition, Pagel *et al.* (1991) demonstrated that more northerly species were also more generalist which correlates with the greater variability of habitats found in those environments. Theories to explain species richness in the tropics include the following.

- **Stability** – tropical climates are more stable than temperate zones.
- **Age** – tropical communities are older, therefore have had more time to evolve.
- **Environmental conditions** – the warm temperatures and high humidity in the tropics provide favourable conditions for many species that are unable to survive in the temperate areas.
- **Control** – ever-present populations of pests, parasites and diseases prevent any species or group from dominating communities.
- **Productivity** – tropical regions are highly productive, thus can provide a greater resource base that can support numerous species.

1.6 Loss of biological diversity

No species will exist forever. Species evolve and some forms disappear after some time. Extinction usually refers to the total disappearance of all individuals of a species. However, the meaning of the word 'extinct' can vary according to the context in which it is used (Estes *et al.*, 1989). A species can be said to be extinct in the wild if individuals of a species remain alive only in captivity. A species can also be locally extinct if it is no longer found in an area which it previously inhabited. Ecologically extinct is another term that focuses on species which are found in such low numbers in a community that their impact is insignificant.

The fossil record shows that since life originated four billion years ago the vast majority of species that existed are now extinct. By the early nineteenth century, geologists had unearthed so many extinct species that as much as 82% of all species known to science were extinct. By the mid twentieth century, Romer (1949) estimated that probably more than 99% of known tetrapods from the mid Mesozoic became extinct without leaving any descendants in our age. Periods of mass extinctions have taken place due to sudden changes in sea level, climate (including the impact of a colliding comet), and volcanic activity (see Sepkoski, 1989; Jablonski, 1991). During these periods of sudden change, those species which were better adapted to new circumstances than others left descendants. Species that evolved fast enough to colonise new habitats in time and space survived and flourished.

Two broad processes influence the dynamics of populations and cause extinction: deterministic (or cause and effect relationships, e.g. glaciation or direct human interventions such as deforestation) and stochastic (chance or random events, which may act independently or influence variation in deterministic processes). Rosenweig (1997) refers to these deterministic and stochastic processes as accidents and population interactions. In other words, species may disappear for no predictable reason or both predation and competition can force populations to succumb in time. The magnitude of the effects of these causes of extinction depends on the size and degree of genetic connectedness of populations. Four types of stochastic process can be distinguished: (1) **demographic uncertainty** – this is only a hazard for relatively small populations (numbering tens or hundreds of individuals); (2) **environmental uncertainty** – due to unpredictable changes in weather, food supply, disease and the populations of competitors, predators or parasites; (3) **natural catastrophes** – floods, fires or droughts; and (4) **genetic uncertainty** – random changes in genetic make-up to which several factors contribute (Shaffer, 1987).

Agents of decline of species have been classified under four main headings: (1) overkill; (2) habitat destruction and fragmentation; (3) impact of introduced species; and (4) chains of extinction. Diamond (1984, 1989) described these terms as 'the evil quartet'. Of these factors, introduced species and habitat destruction are responsible for most known extinctions and threatened species of vertebrates (Jenkins, 1992). Thirty-nine per cent of species have become extinct through introductions and 36% through habitat loss. Hunting and deliberate extermination have also contributed significantly (23% of extinctions with known causes) (see below).

Overkill. This results from hunting at a rate above the maximum sustained yield. The most susceptible species are those with low intrinsic rates of increase (i.e. large mammals such as whales, elephants and rhinos) because of their limited ability to recover quickly. Although such species usually have a high standing biomass when unharvested, they have a low maximum sustained yield which is easily exceeded. They are even more vulnerable if they are valued either as food or as an easily marketable commodity. An example of this comes from work in Equatorial Guinea in which meat extraction from the bush was proportional to the purchasing power of the urban markets. The volume of bushmeat serving Malabo, the administrative capital in Bioko, was 70% greater than that being sold through Bata, in Rio Muni, though there was little difference in population size between the two centres (52 000 and 55 000 respectively) (Fa *et al.*, 1995). Actual harvests far exceeded potential extraction on the island and have led to the drop in numbers of many species (Albrechtsen *et al.*, 2007).

Habitat destruction and fragmentation. Although habitats may be modified, degraded or eliminated, they are more commonly fragmented. A large tract is often converted piecemeal to another land-use. This practice is widespread throughout the world. Loss of habitat by a given proportion does not increase the vulnerability of a species, nor does it decrease the number of its members by that same proportion (except in the particular case of habitat cleared from the edge inward). Frequently, modification produces a patchwork pattern as it erodes the tract of habitat from inside and changes micro-climates (Saunders *et al.*, 1991). Initially, the areas occupied by the new land-use form islands which later multiply and enlarge until the new land-use provides the continuous phase and the original habitat the discontinuous one. The vulnerability of species then increases disproportionately. A clear example of this comes from a study by Ranta *et al.* (1998) on the Atlantic rainforest fragments remaining in Pernambuco, Brazil. Their analyses of size, shape and distribution of the forest fragments showed that a large proportion