CHAPTER 21

MANAGING PROTECTED AREAS FOR BIOLOGICAL DIVERSITY AND ECOSYSTEM FUNCTIONS

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CONTENTS

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Nahanni Ram Plateau in Nahanni National Park, Northwest Territories, Canada
Source: Alison Woodley

Introduction

Protected areas are the cornerstones of global efforts to conserve biodiversity. Biological diversity (biodiversity) and ecosystem functions are the fundamental components of any ecosystem (Box 21.1) that protected area managers must consider to be successful. This chapter looks at the relationship between biological diversity and ecological function, the threats to each, and how to assess and monitor ecosystems.

Increasingly, protected areas are the last places left for much of the planet's biodiversity. The International Union for Conservation of Nature (IUCN) Red List of Threatened Species that have a high risk of global extinction reveals that many of these species are now found only in protected areas (Le Saout et al. 2013). For example, Javan rhinos (*Rhinoceros sondaicus*) are found only in Indonesia's Ujung Kulon National Park. Similarly Indian rhinos (*Rhinoceros unicornis*), once widespread throughout Asia, are now restricted to protected areas, including Kaziranga National Park in India and Royal Chitwan National Park in Nepal. Conserving biodiversity in protected areas means conserving both species and the ecological functions upon which those species depend.

Box 21.1 Key definitions

Biological diversity, or *biodiversity* for short, means the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. Biodiversity is measured at three main hierarchical levels.

- *Genetic diversity* includes the different genes contained in all individual plants, animals, fungi and microorganisms. *Species diversity* is a measure, within an ecological community, of both the number of species and the evenness of their distribution. *Ecosystem diversity* includes all the different habitats, biological communities and ecological processes, as well as variation within individual ecosystems.
- *Ecosystem functions* are the physical, chemical and biological processes that contribute to the functioning of an ecosystem. Some definitions of biodiversity include ecosystem functions. Examples of ecosystem functions are primary productivity (conversion of sunlight to energy), nutrient cycling and the water cycle.
- *Ecosystem services* are those benefits that ecosystems provide to humanity, including products like food and clean drinking water, and processes such as pollination, the decomposition of wastes or regulation of flooding. Ecosystem services are a subset of biological diversity and ecosystem function, seen from a human perspective (Daily 1997).

The relationship between biodiversity and ecological function

The need to manage for biological diversity, including ecological function, is inherent in the IUCN definition of a protected area. A protected area is '[a] clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values' (Dudley 2008:8).

From a conservation perspective, a key role of protected areas is to maintain ecological structures (genes, species and ecosystems) and the ecological functions that support those structures. In addition to protecting biodiversity, protected areas also have a key role in protecting ecosystem services, which underpin human welfare (see Chapter 6). Protected areas also conserve the non-living or abiotic elements of ecosystems. For example, protected areas protect geological diversity as well as the biodiversity associated with certain geological features (Chapter 18).

The interaction of ecological structure, mainly species, with function is complex and still poorly understood. Key questions remain, such as, are some species redundant? If species are extirpated from an ecosystem (or a protected area), will this affect the ecological functions at that location? Understanding this relationship becomes more critical with the increased rate at which species are being eliminated from ecosystems through local extirpations (species disappearance from a given area) or even extinctions (complete species loss) (see Butchart et al. 2010).

Concern over the relationship between ecological structure and function has led to a range of scientific research, such as the Millennium Ecosystem Assessment commissioned by international bodies (Schulze and Mooney 1993; Heywood 1995) and work by the World Resources Institute (2005). An important review paper published in *Nature* (Cardinale et al. 2012) summarised the global literature on the relationship between ecological structure and function with six consensus statements (Box 21.2).

Box 21.2 Six consensus statements on the relationship between ecological structure (species) and function

1. There is now unequivocal evidence that biodiversity loss reduces the efficiency with which ecological communities function, including the production of biomass, and the decomposition and recycling of biologically essential nutrients (Figure 21.1).
2. There is mounting evidence that biodiversity increases the stability of ecosystem functions through time.
3. The impact of biodiversity on any single ecosystem process is not linear. Most experimental studies indicate that initial losses of biodiversity in diverse ecosystems have relatively small impacts on ecosystem functions, but increasing losses lead to accelerating rates of change (Figure 21.1).
4. Biologically diverse communities are more productive because they contain key species that have a large influence on productivity. Differences in functional traits among organisms increase total resource capture. Ecosystem functions are thus controlled by both the identity and the diversity of organisms.
5. Loss of diversity across trophic levels has the potential to influence ecosystem functions even more strongly than diversity loss within trophic levels. Food web interactions are key mediators of ecosystem functioning. The loss of higher consumers can cascade through a food web, leading to alterations in vegetation structure, fire frequency and even disease epidemics in a range of ecosystems.
6. The functional traits of organisms have large impacts on the magnitude of ecosystem functions, so the loss of a specific species can have widely varying impacts on ecosystem function. The extent to which ecological functions change after the extinction of a particular species depends greatly on which biological traits are extirpated.

Source: Adapted from Cardinale et al. (2012)

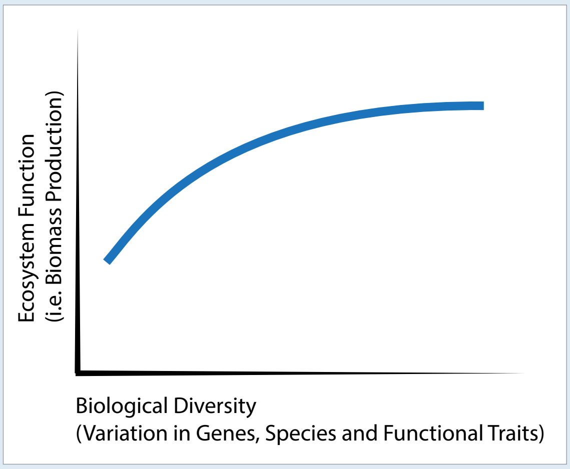


Figure 21.1 The relationship between ecological function and biodiversity

Source: Cardinale et al. (2012)

White rhinoceros (*Ceratotherium simum*) and other large herbivores play an important role in ecosystem function in Africa and require large, secure habitat areas, Mkhuze Game Reserve, South Africa

Source: Ian Pulsford

Lessons for protected area managers from these considerations include the following.

- Protected areas should be managed, as much as possible, to retain all native species, in order to maintain ecological function and ultimately ecological integrity. The best policy is to assume all species are important.
- Protected area management should focus on identifying and maintaining ecological processes that are known to be important to the ecosystem in question. This includes disruptive processes such as fire (for fire-adapted ecosystems) and flooding.
- Managers should pay special attention to maintaining the functional roles of species across different trophic levels (levels in a food web). For example, it is well understood that large predators provide top-down regulation of ecosystems and are essential to maintaining ecological integrity (Case Study 21.6).

Nahanni National Park, Canada, contains some of the most spectacular wild rivers in North America, with deep canyons, huge waterfalls and spectacular karst terrain, cave systems and hot springs
Source: Alison Woodley

Patterns of global biodiversity

The diversity of life in a protected area is determined by the same driving forces that determine patterns of life on Earth. In a general sense, these patterns are clear and easily described; however, when it comes to the biodiversity of an individual protected area, the large-scale global patterns are highly influenced by local factors. For a detailed review of the patterns of global diversity, readers are referred to Gaston (2000) (see also Chapter 3). Most analyses of spatial variation concern biodiversity as measured by the number of species observed or estimated to occur in an area (species richness). Most attention has been paid to latitudinal variation in species richness, and relatively little is known about variation in the diversity of genes, individuals or populations along latitudinal gradients.

The general patterns of biodiversity are as follows.

- In general, the majority of terrestrial and freshwater species occur in the tropics, with species richness declining from the tropics to the poles. This general pattern also holds for the oceans.
- In general, there are higher levels of biodiversity at lower elevations, in areas with higher levels of annual rainfall and in areas of warmer summer temperatures.
- In general, different taxa (categories of species, such as reptiles) show the same kind of variation regionally. For example, at a global scale, areas of high bird diversity will also have high diversity of plants or amphibians (see Figure 21.2). There is, however, enormous variation in this general pattern. At a regional level, it is not possible to reasonably predict the diversity of any taxon simply by knowing the diversity of another taxon.
- These general patterns are important at broad scales, but do not always well explain local conditions in protected areas. Biodiversity can be highly modified by terrain, slope, water, bedrock, soil type and development and the history of ecological colonisation and disturbances.

It is important to think about both the regional and the local biogeography in the management of a protected area (Box 21.3). There have been many efforts to systematically describe the global patterns of biological organisation (Klijn and de Haes 1994). Many different lists and ecological land classification schemes have been developed, based on the following examples.

- Biogeography: Ecological land classification is a set of approaches that organises global ecosystem types by patterns of climate, topography and vegetation. Some approaches, such as 'biogeographical provinces', take into account both flora and fauna.
- Botany: Botanists have identified 'floristic provinces' based on floral communities.
- Zoology: Zoologists have identified 'zoogeographic provinces' based on faunal communities, or even identified systems based on groups, such as 'mammal provinces'.
- Geology and pedology (soil study): The physical matter and energy that constitute the Earth.

Perhaps most useful for protected area management is the 'Ecological Land/Marine Classification System', which integrates a range of ecological factors, rather than focusing on only one element. Ecological units can be usefully described on the basis of bedrock, climate, physiography and corresponding vegetation, creating an ecological land classification system.

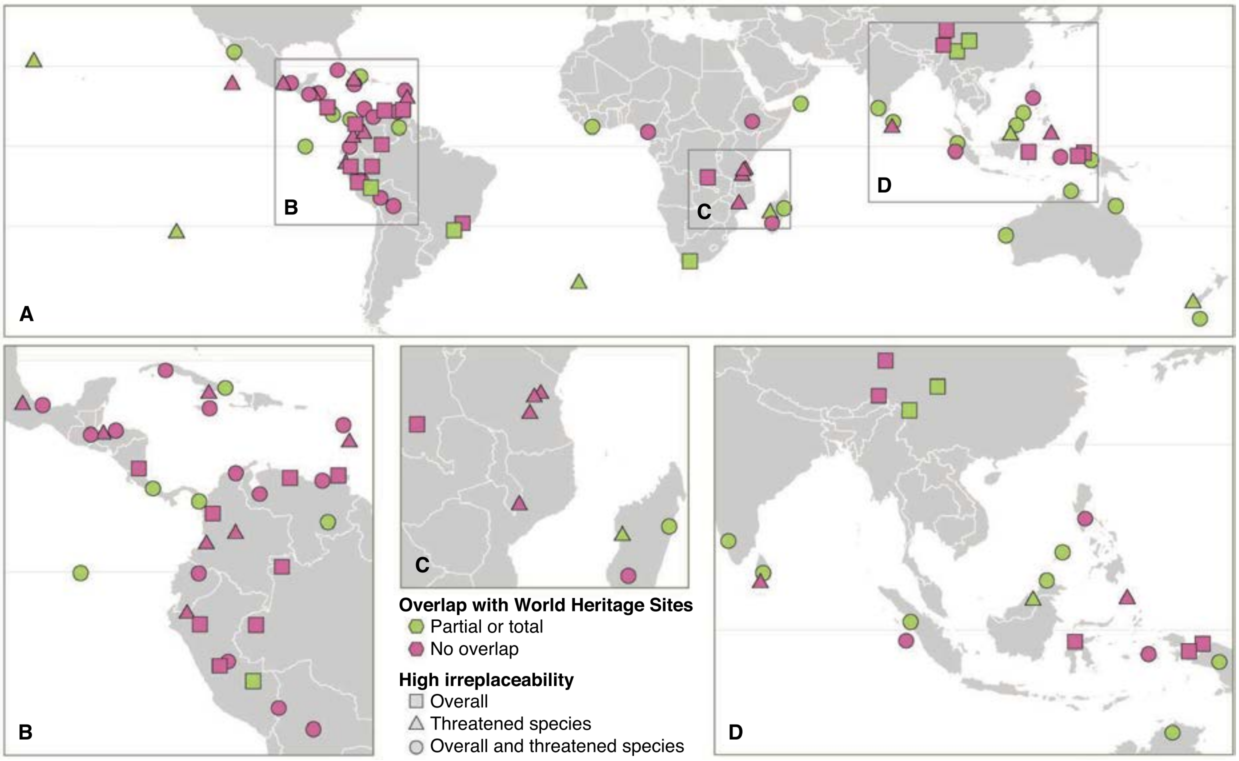


Figure 21.2 Some of the world's most important protected areas for conservation of amphibian, bird and mammal species: (A) Global distribution; (B) Central and South America; (C) East Africa; (D) South and South-East Asia

Source: Adapted from Le Saout et al. (2013)

Box 21.3 A simple nested system of ecosystem classifications and their uses for protected area management

Biome: A large naturally occurring community of flora and fauna occupying a major habitat—for example, forest or desert.

Ecoregion: A regional-scale pattern of ecosystems associated with characteristic combinations of soil, landforms and vegetation that characterise that region—for example, Acacia-Miombo woodlands.

Ecodistrict: A subdivision of an ecoregion with more uniform patterns of soil, topography and vegetation—for example, south-facing wooded acacia hills.

Source: Klijn (1994)

The classic references are the map and IUCN document prepared by Udvardy (1975) titled *A classification of the biogeographical provinces of the world*. From a protected area perspective, the World Wide Fund for Nature (WWF) has led the development of global systems of ecological classification, complete with online maps and descriptions. Readers are referred to the global descriptions of terrestrial ecoregions developed by Olson et al. (2001), as well as for the best available description of the terrestrial ecoregions. For coastal marine regions, readers should refer to Spalding et al. (2007).

These classification systems are essential for many aspects of protected area management such as:

- regional conservation planning to assess gaps in the protected area system
- setting targets for protected area representation and conservation planning
- determining the level of regional or global significance of a protected area
- assessing the status of ecological features (for example, mapping ecosystem types, intact watershed)
- state of the protected areas reporting
- studying natural disturbance regimes in a context larger than a protected area
- defining seed zones for restoration projects.

The spatial distribution of species at risk can be expressed by looking at where the existing protected area system contains species that are on the IUCN Red List (Figure 21.2).

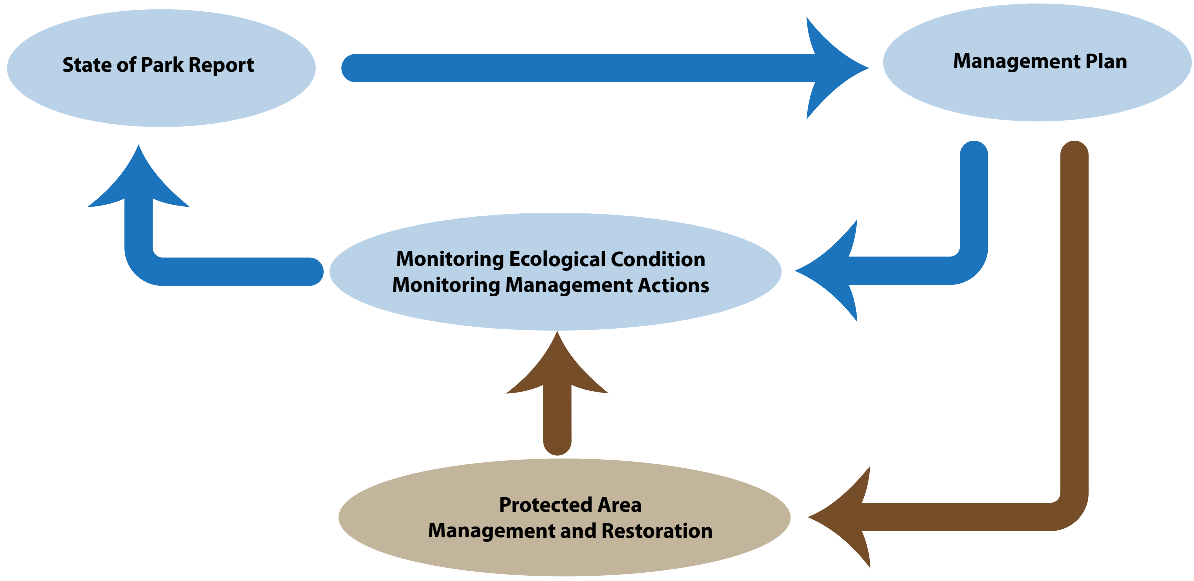


Figure 21.3 The protected area management loop

Source: Stephen Woodley

It is important to think about protected areas and protected area systems in the context of global patterns of biodiversity; however, just because a protected area is not located in a high biodiversity area, this does not diminish its value in conserving nature. Effective conservation requires adequate representation of all species and ecosystems within protected areas (Woodley et al. 2012). In addition, some key species of conservation concern occur in species-poor places, such as plants in highly mineral-rich environments.

Opuntia cactus (*Opuntia* sp.), Big Bend National Park, Texas, USA

Source: Stephen Woodley

Assessing protected area condition: Ecological integrity

By definition, protected areas are established to conserve nature, and the ecosystem must be in suitable condition so that it conserves its biodiversity in the long term. Protected area management depends on knowing the ecological condition of the protected area as a fundamental part of management. Based on this and other information, decisions can be made about management and restoration. The key tasks of protected area management are: 1) to understand how the ecosystem works; 2) to define suitable indicators to assess ecological condition; 3) to monitor those indicators and determine ecological condition; and 4) to take management action when those indicators are outside an acceptable range. Central to the management process is monitoring information on ecological condition and the results of management actions (Figure 21.3).

Managing for ecological integrity

Historically, protected areas have been managed with goals that are imprecise, such as to conserve 'natural' or 'wilderness' areas. In reality, many protected areas have been managed with specific species conservation targets in mind, such as maintaining large game herds in African parks or flagship species such as tigers and elephants in major Indian parks (MacKinnon et al. 1986). The terms 'ecological integrity' and 'ecosystem health' are now increasingly being adopted by protected area managers to describe their goals for ecosystem management. Numerous statutes and official policy statements now articulate the concept of integrity as a goal including the *Great Lakes Water Quality Agreement* (International Joint Commission 1978) and the Convention on Biological Diversity (CBD 2004). The notion of ecological integrity has been discussed from many perspectives (Edwards and Regier 1990; Woodley et al. 1993; Pimentel et al. 2000). With respect to a protected area, ecological integrity means a condition characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes. Note that this definition is ecologically based and that it does not require the absence of people. In fact, ecological integrity is a concept that can apply to ecosystems with or without people present and playing a key ecological role.

The lessons for best practices in determining a protected area's ecological condition are as follows.

- All protected areas need to have clear management goals and objectives for biodiversity and ecosystem processes. Otherwise, the aim of management is unclear.
- Ecological goals should be included in the protected area's management plan.
- Consider using ecological integrity as a management end point. It has been adopted by many protected area agencies and there is considerable information available on how to measure it.

Ecological integrity and protected areas

Understanding ecological integrity in the context of protected areas requires careful thought about how an ecosystem is structured and how it is functioning. From the science of ecology, we understand that ecosystems exhibit a number of characteristics that are important to measure (Woodley 2010).

Waterfowl rest at Padre Island National Seashore, Texas, USA, during their annual migration
Source: Stephen Woodley

1. Protected areas should conserve all native species. Ecosystems lose integrity when they lose species. Some of the main causes of species loss are habitat loss and fragmentation; many protected areas lose species because they are too small. For example, western North American parks have experienced extinction rates that are inversely related to park size (Newmark 1995). Other examples of stressed ecosystems losing species include Canadian boreal forests subject to high sulphur dioxide emissions (Freedman and Hutchinson 1980); temperate deciduous forest subject to radiation exposure (Woodwell 1970); and estuarine diatom communities subject to heavy metal pollution (Patrick 1967).
2. The populations of species in protected areas should be viable. For practical reasons, it will only be possible for protected area managers to check the viability of a few species, called indicator species. There is a large literature on the selection of indicator species (see Simberloff 1998; Lindenmayer and Lichens 2010). The status of indicator species is usually determined by examining population vitality rates (for example birth, death, immigration and emigration) and using those metrics to determine the probability of survival (or conversely the probability of extinction), typically for 100 or 1000 years (Soulé and Simberloff 1986).

3. Ecosystem trophic levels in protected areas should be intact. Ecosystems have characteristic levels and interactions of primary producers, herbivores and carnivores—often described as food webs. Highly impacted ecosystems tend to have food webs that are simple in comparison with unmodified ecosystems. For example, the loss of top carnivores can result in hyper-abundant ungulate populations, which have cascading adverse effects on plant communities (Estes et al. 2011; see also Case Studies 21.5 and 21.6).
4. Disturbance regimes in protected areas should operate to maintain biological communities with a mix of age classes. Ecosystems are inherently dynamic, driven by fire, climate, weather and herbivores. After disturbance, ecosystems pass through sometimes predictable successional stages. Repeated disturbance events create a mosaic of biological communities in both time and space. The resulting configuration of community types of different size and age determines the survival of individual species. Since some disturbances (for example, fire and herbivory) can be influenced by protected area managers, this aspect of ecological integrity is at least under partial management control (Case Study 21.1).
5. Productivity and decomposition in protected areas should operate within limits for system persistence. Most ecosystems are driven by primary productivity—the amount of organic matter produced by biological activity per unit area in a given period (Hooper et al. 2012). The onset of ecosystem problems occurs when subtle shifts in productivity occur, and major problems are indicated when energy is lost from the ecosystem in an uncontrolled manner. For example, in stressed systems, such as heavily logged forests, decomposition rates rise significantly. Productivity and decomposition operate within a range for specific ecosystems. When these vital processes move outside that band, the ecosystem is fundamentally impacted and loses its integrity. Changes in productivity can be measured using a readily available satellite-based index, called the 'normalised difference vegetation index' (NDVI) (Tucker et al. 2005).
6. Nutrient cycling in protected areas should be within limits for system persistence. In virtually all ecosystems, nutrient availability is a limiting factor and rates of nutrient cycling are critical to ecosystem function (Hooper et al. 2012). Ecosystems cycle and conserve nutrients at characteristic rates. As ecosystems become stressed and lose integrity, they lose their ability to retain nutrients, and exhibit changes in rates of nutrient cycling and in the relative abundance of nutrient pools (Likens et al. 1978). Ranges of nutrient cycling can be determined from values in the scientific literature and by comparison with healthy reference ecosystems.

Most critically, the concept of ecological integrity provides a measurable and clear foundation for protected area management. If protected area goals and objectives are not measurable, there is no way of knowing whether or not management is successful (Lindenmayer and Lichens 2010). This is particularly important where active management and intervention in ecosystem processes occur. Ecological integrity provides a framework that allows for the translation of broad, often vague nature-protection goals, into more specific and measurable end points, based on desirable ecological conditions that can be monitored.

Managing protected areas for biodiversity

Successful management of protected areas requires thinking of them as an integrated system that has a system-level goal, such as ecological integrity. The practical management of ecological integrity often means managing biological diversity (most generally, species) and ecological functions. Globally, protected areas form a primary tool for maintaining biodiversity. This section covers the principles of managing for the conservation of biodiversity in protected areas at all three levels: genetic, species and ecosystem. Example case studies are given for each level of biodiversity. Many more case studies are available online or by contacting protected area specialists in your region.

Managing protected areas for genetic diversity

Protected areas are often established to conserve unique features or to conserve representative ecosystems and species. Rarely are they established or designed with genetics explicitly in mind, even though genetic diversity represents the building blocks for evolution and adaptation (Hughes et al. 2008). A reduction in genetic diversity limits the potential for a population to adapt and is often linked to a reduction in fitness (Frankham 2005; Mattila and Seeley 2007). A reduction in ecological fitness at the individual level adds to the challenges already faced by small and isolated populations, contributing to what is called the 'extinction vortex' (Gilpin and Soulé 1986; Caughley 1994; Fagan and Holmes 2006). Genetic diversity has even been shown to have important effects on ecological processes, such as primary productivity (Hughes et al. 2008).

Case Study 21.1 Protected area planning using disturbance regime information, Australia

Many factors underpin the design of protected areas including the species, communities, ecosystems or ecological processes targeted for conservation. Consideration of the impacts of major natural disturbances on biodiversity and key ecological processes is an important issue in the design of protected areas or systems. In ecosystems with recurrent, high-severity disturbances, these processes are essential for important ecological values as well as populations of species of conservation concern (Lindenmayer and Franklin 2002).

The mountain ash (*Eucalyptus regnans*) forests of the Central Highlands of Victoria, south-eastern Australia, provide a valuable illustration of the interrelationships between the design of protected areas and natural disturbance. These forests support some of the tallest flowering plants in the world, with old-growth trees reaching heights of 100 metres. Mountain ash forests provide habitat for many species, including the globally endangered Leadbeater's possum (*Gymnobelideus leadbeateri*)—a focal species in this ecosystem (Lindenmayer 2009).

Fire is the primary form of natural disturbance in mountain ash forests. Prior to European colonisation, the fire regime was infrequent, with wildfire that occurred in late summer (Ashton 1981) and at an intensity that allowed some tree survival. Mountain ash forests have been altered by more than a century of high-intensity logging, increases in wildfires and the combination of both fire and logging (Lindenmayer et al. 2011). About 20 per cent of mountain ash forest in the Central Highlands of Victoria is currently protected; however, the overall size of the protected area system is too small to maintain the forests and viable populations of species such as Leadbeater's possum. A more extensive area of protected forest is needed, particularly if additional fires occur in the next 50–100 years. Any expanded reserve system must be large enough to ensure that even in the event of a wildfire, there is sufficient forest habitat remaining to support viable populations of rare marsupial species (Baker 1995).

Several factors can be used to guide where an expanded area of reserved forest might be best located. Expansion should include places that both connect key areas of habitat for focal species such as Leadbeater's possum and connect existing reserves. Enhanced ecological connectivity enables the dispersal of species throughout forest landscapes, including those regenerating after wildfire. Second, an expanded area of reserved forest should encompass areas of old-growth forest as well as areas likely to be suitable habitat for focal species, such as Leadbeater's possum (Lindenmayer et al. 1999).

This case study highlights the importance of incorporating the effects of disturbances in the design and establishment of effective protected areas.

Endangered Leadbeater's possum (*Gymnobelideus leadbeateri*), Victoria, Australia
Source: David Lindenmayer

Best practices for managing genetic diversity

Maintaining genetic diversity and avoiding the extinction vortex are major challenges for many small and isolated protected areas. Potential solutions include the following.

- Increasing the effective habitat size of the protected area so that it can contain more individuals of a given species. This can be done through land acquisition or ecological restoration (Case Study 21.2).
- Small populations can be augmented with the translocation of individuals from larger and healthier populations in order to increase local population size and genetic diversity (Bouzat et al. 2009). This is a well-established principle with many examples around the world, such as the reintroduction of tigers (*Panthera tigris tigris*) to Sariska National Park in India, of golden lion tamarins (*Leontopithecus rosalia*) in the Atlantic forests of Brazil and of the greater prairie chicken (*Tympanuchus cupido pinnatus*) in the United States (Case Study 21.3).
- Working at landscape and regional levels to ensure ecological connectivity between separate protected areas and ensuring integration with populations using the working landscape around protected areas. Connectivity increases the effective population size and allows gene flow among protected and natural areas (di Minin et al. 2013; Sawaya et al. 2013; Case Study 21.4).

Case Study 21.2 Increasing the size of protected areas for genetic diversity

In general, the smaller a protected area is, the more active management it will require to maintain important components of biodiversity. Whiteman Park, in the suburbs of Perth, Australia, includes the 50-hectare Woodland Reserve, an electrified predator-proof facility, designed for breeding and providing habitat for rare and endangered species, including the critically endangered woylie (*Bettongia pencillata*) (Pacioni et al. 2011). Managers were concerned about the long-term viability of the small and isolated populations of rare species within the reserve and asked a geneticist to help develop a management plan for the woylie. The plan called for an increase in the size of the reserve from 50 to 200 hectares, which analysis suggested would double the length of time that the colony would maintain an acceptable level of heterozygosity (a measure of genetic diversity), which is a key measure of genetic health (Rafferty and Pacioni 2012). The plan also recommended a regular program of supplementation with the introduction of woylie from elsewhere in order to maintain genetic diversity within the colony.

Case Study 21.3 Translocations to maintain genetic diversity

In south-eastern Illinois, USA, where almost all native prairie grasslands have been lost, managers have been trying to maintain the greater prairie chicken (*Tympanuchus cupido pinnatus*), an iconic species of the grasslands, including in two small protected areas (Westemeier et al. 1998). Past efforts included restoring the grasslands and increasing habitat for the species but proved to be insufficient to recover the population (Figure 21.4). Monitoring over 35 years indicated that as the population size continued to decline, so did fertility, nest success and genetic diversity (Bouzat et al. 1998). Concerned that the lower genetic diversity was contributing to the reduction in fitness and hence exacerbating the negative effects of small population size, managers enacted a translocation program, bringing in birds from larger, healthier populations further west (Westemeier et al. 1998). The translocations proved successful in that they restored genetic diversity, countered the effects of inbreeding depression and led to an increase in fitness (egg viability and nest success) and ultimately an increase in the long-term viability of the population (Bouzat et al. 2009). This illustrates the importance of managing specifically for genetic diversity in order to maintain biodiversity in protected areas.

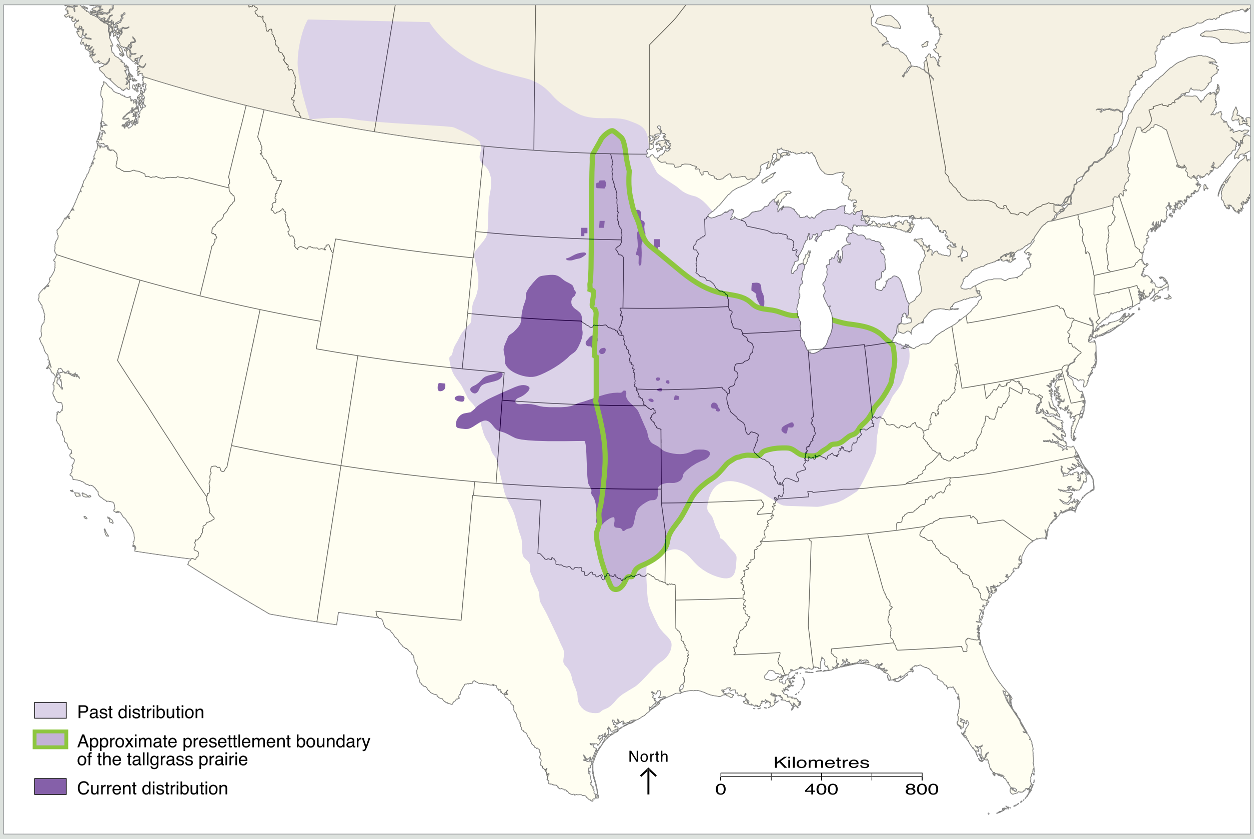
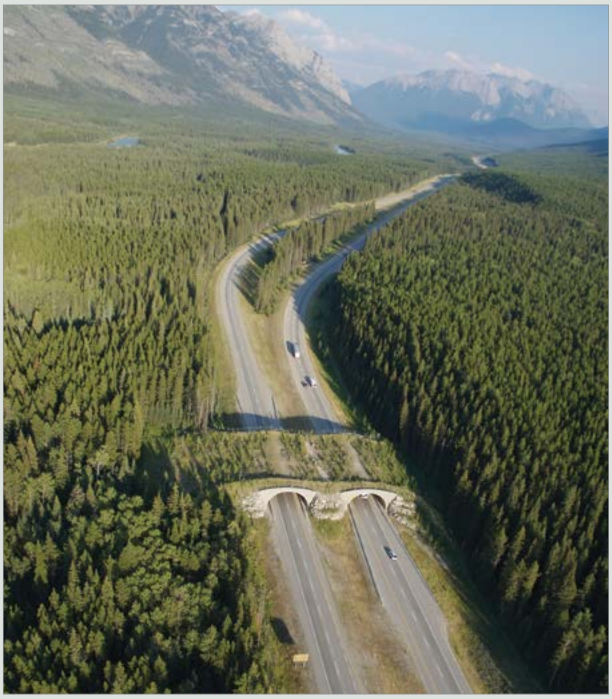


Figure 21.4 Current and historical distribution of the greater prairie chicken (*Tympanuchus cupido pinnatus*), USA

Source: Modified from W. Daniel Svedarsky, Northern Prarie Wildlife Research Centre, Jamestown, ND, USA

Case Study 21.4 Restoring connectivity in Banff National Park to maintain genetic diversity

Banff National Park is home to the spectacular scenery of the Rocky Mountains and megafauna, attracting the most visitors of any national park in Canada. It is bisected by the Trans-Canada Highway and the main line of the Canadian Pacific Railway—both extremely busy transportation routes that fragment the natural habitats in the park and result in significant numbers of wildlife mortalities (Clevenger and Sawaya 2010). In an effort to restore connectivity and gene flow across the transportation corridors, Parks Canada constructed 38 wildlife underpasses and six overpasses, and installed fencing along stretches of the highway (Clevenger et al. 2009). About 30 years of monitoring has recorded more than 120 000 crossings, including by most of the large mammal species: grey wolves (*Canis lupus*), coyotes (*Canis latrans*), cougars (*Puma concolor*), deer (*Odocoileus virginianus*), elk (*Cervus canadensis*), moose (*Alces alces*), grizzly (*Ursus arctos horribilis*) and black bears (*Ursus americanus*). In recent years, researchers have been testing non-invasive hair-snag techniques to collect DNA to assess the genetic and population-level effects of the wildlife crossings in Banff National Park (Sawaya et al. 2013). Although there is currently no empirical evidence indicating significant gene flow across overpasses, underpasses or along corridors (Corlatti et al. 2009), it seems likely that countering the effects of fragmentation would help improve genetic diversity, population viability and ultimately biodiversity in protected areas (van der Ree et al. 2009).



Wildlife crossing on the Trans-Canada Highway in Banff National Park, Canada

Source: Parks Canada

Managing protected areas for native species diversity

Many protected areas are currently managed to conserve rare and endemic species or species groupings. Managing protected areas for native species diversity can be very challenging because different species often require very different management actions. The challenge when financial and human resources are limited is deciding on which actions to focus. Below is a brief overview of several options, such as focusing on keystone species, trophic levels, pollinators, rare species and population-level management.

Keystone species

Species vary in their influences on ecosystems (Simberloff 1998). A few species exhibit effects disproportionate to their size and abundance on ecosystem structure and processes, and consequently on species composition (Mills et al. 1993). These are described as 'keystone species'. That term was first coined in 1969 by Robert T. Paine, whose research showed that removing a single species of starfish had a significant effect on a tidal plain ecosystem in Washington State, USA. Once the starfish was removed, the tidal zone became dominated by mussels—the starfish's prey—which in turn displaced other species and lowered the species diversity of the ecosystem (Paine 1969).

Similarly, the Magellanic woodpecker (*Campephilus magellanicus*) is considered a keystone species because it helps to create habitat structures that are used by eight other bird species and one mammal in Nahuel Huapi National Park, Argentina (Ojeda 2007). Exploitation of southern beech forests for logging in Argentina and Chile has led to a decline in the abundance of the woodpecker, with adverse impacts for the associated species. A key lesson from these studies is that managers need to understand the roles of individual species in order to manage, understand and restore ecological assemblages.

Trophic levels and trophic cascades

A trophic level refers to the position a species occupies in the food chain. In its simplest form, the food chain includes producers (for example, plants or algae), consumers (for example, herbivores and carnivores) and decomposers (for example, bacteria and fungi), with energy being transferred up the chain (Pimm 1982). Real ecosystems, of course, are far more complex, often with several trophic levels across multiple food webs (Estes et al. 2011). The management of protected areas requires an understanding of inherent trophic levels

Case Study 21.5 Sea otters and their impact on coastal ecosystems

One of the best-known keystone species is the sea otter (*Enhydra lutris*), which eats a wide variety of prey. Most importantly, it consumes sea urchins, which feed on kelp. Left unchecked, sea urchins can denude seascapes of kelp, leading to trophic cascades. By helping to control the abundance of sea urchins, sea otters indirectly help to maintain the kelp forest ecosystems, which provide food and shelter for many other species (Duggins 1980). Unfortunately, harvesting of sea otters for their prized fur has resulted in the species' extirpation from many parts of its range and its listing as an endangered species in the United States (Benz 1996). In order to restore this important keystone species, there have been many attempted reintroductions (Raesly 2001). Several decades after a reintroduction effort in Checleset Bay, British Columbia, sea otters are once again abundant and the bay is home to a healthy kelp forest ecosystem. An ecological reserve was established specifically to protect sea otters and thereby the native kelp ecosystem.

Purple sea urchin (*Strongylocentrotus purpuratus*)
Source: © Jeff Rotman

because energy flows primarily between, not within, levels, and disruption of that flow could lead to major changes to ecosystems. Typically, such changes result from the removal or (re)introduction of predators, either releasing or controlling (respectively) herbivores, often resulting in dramatic changes to the ecosystem structure and nutrient cycling (Case Studies 21.5 and 21.6).

Pollinators

Large carnivores are not the only taxa affecting ecosystems; pollinators also play a key role. There are about 350 000 species of flowering plants (WCSP 2008), and while some rely on wind for pollination, the vast majority (more than 85 per cent) depends on pollination by animals, highlighting the importance of pollinators in maintaining biodiversity (Ollerton et al. 2011). Pollinators include about 20 000 species of bees, along with moths, butterflies, wasps, beetles, flies, bats, squirrels, monkeys and birds, among others.

Protected areas that have limited natural processes and/or are isolated from other natural areas often have to develop hands-on management techniques in order to maintain native biodiversity. For example, Fish Point Provincial Nature Reserve, which is located on a highly developed island in Lake Ontario, is one of the most southerly points in Canada and is home to several rare plants. Recognising the reality of reduced regional pollinator diversity and abundance, the 2005 park management plan called for hand pollination, seed collection and assisted propagation as tools necessary to help maintain the park's plant diversity. A study in South Africa found that even in places rich in protected areas and biodiversity, pollination services declined with distance from natural areas. Thus, not only will a protected area's biodiversity benefit from the management of pollinators, neighbouring farms will also benefit (Janzen 1999; Carvalheiro et al. 2010; Chan et al. 2006).

The maintenance of pollinators within protected areas can benefit biodiversity over considerable distances. For example, Indooroopilly Island Conservation Park in Australia is an important roosting area for three flying fox bat species. The bats can fly as far as 100 kilometres each night to forage, potentially serving as important long-distance vectors for pollen. Therefore, the park's management efforts to conserve habitat for the flying foxes will also help to maintain genetic and biological diversity in the greater ecosystem (Martin 1990).

Rare species

Management of protected areas often gives priority to actions that maintain ecological integrity and that benefit common species but not necessarily rare species

Case Study 21.6 Trophic cascade from a top predator

A well-known example of a trophic cascade resulted from the reintroduction of the grey wolf into Yellowstone National Park, USA (Fortin et al. 2005). Grey wolves (46 individuals) were reintroduced to Yellowstone National Park starting in 1995, after having being extirpated in 1926. The ecological cascade that resulted from the re-establishment of a top predator is well documented and illustrates the critical ecological role played by top predators (Ripple et al. 2001). In the absence of wolves and aboriginal hunting, the population of the herbivorous (Cervus elaphus) elk had risen to extreme levels, eliminating stands of quaking aspen tree and reducing the stream-side cover of willow shrubs. The dramatic reduction of aspen and willow had led to elimination of the dam-building beaver (*Castor canadensis*) from much of the park, which affected stream flow and caused stream erosion. The reintroduction of wolves has significantly reduced elk numbers, aspen and willow are recovering and beaver are returning to areas of the park. The entire process will take decades to unfold. This example illustrates not only the role of large predators in the top-down regulation of ecosystems, but also the role of protected areas as long-term research sites for ecological understanding. Protected area strategies that focus on the key role that indigenous carnivores play will greatly assist the maintenance of ecosystem integrity and biodiversity.

Bull elk (*Cervus elaphus*) at Mammoth in Yellowstone National Park, United States of America

Source: Graeme L. Worboys

(Simberloff 1998; Niemi and McDonald 2004) even though many species are rare and rare species contribute the most to a region's biodiversity—a pattern noted by Charles Darwin. For example, an analysis of tree species in the Amazonian lowlands found that half of all the trees belonged to 227 'hyper-dominant' species, while the rest were represented by 11 000 species (Steege et al. 2013). In other words, the vast majority of species (more than 98 per cent) were rare, at least in terms of abundance; however, many of the species with few trees proportionally were widespread throughout the lowlands and had high total numbers of stems.

This raises the question: what does rare mean and how does one measure it? A species which might seem rare in one country may be abundant in another. Rabinowitz (1981) suggested that species could be considered rare if they had a small regional population size, a restricted geographic distribution or a restricted habitat distribution (high habitat specificity).

Managers also need to consider how threatened a species is—that is, its conservation status. The IUCN's Red List of Threatened Species is based on a series of criteria with precise thresholds including population size and trend, geographic range (as measured by the extent of occurrence and area of occupancy) or probability of extinction, if there are sufficient data to conduct an analysis (IUCN 2001). Based on a combination of the criteria, species are categorised as:

1. critically endangered (CR): extremely high risk of extinction in the wild
2. endangered (EN): high risk of extinction in the wild
3. vulnerable (VU): high risk of endangerment in the wild
4. near threatened (NT): likely to become endangered in the near future
5. least concern (LC): lowest risk; does not qualify for a more at-risk category.

As of 2012, the IUCN Red List included almost 4000 species listed as critically endangered, 5766 as endangered and more than 10 000 as vulnerable, although most non-vertebrate groups have not been assessed. Given that many species are rare locally but still widespread, managers must sometimes use protected area networks to maintain populations. Often protected areas are too small to conserve a viable number of species and a network of protected areas is required. Managers of individual protected areas should be aware of what their peers are doing in other protected areas within the same ecoregion (Noss 1983). This was recognised in South Africa, for example, where the objective of

Endangered mountain gorilla (*Gorilla beringei beringei*) in Bwindi Impenetrable National Park, Uganda

Source: Stuart Cohen

the network approach was enshrined in legislation, '[t]o ensure the establishment, development and efficient management of a network of formally protected areas in order to conserve indigenous biodiversity, representative samples of natural ecosystems and habitats of critically important or threatened species' (*North West Parks and Tourism Board Act 1997*).

Population management

Many protected areas are not large enough to maintain viable populations of all species. In these cases, managers must do more than protect a site and rely on natural processes to maintain species (Gurd et al. 2001; Landry et al. 2001; Deguise and Kerr 2006). Consequently, active management is often required. As a general rule, the smaller the reserve, the more active management is needed (MacKinnon et al. 1986). This sometimes includes the need to undertake population management measures to deal with population fluctuations, meta-populations and/or to ensure the viability of populations.

All wildlife populations undergo fluctuations in abundance to some degree, as a function of birth and death rates, changes in resources, temperature and rainfall, predation, disease and stochastic events (Boyce and Daley 1980). In general, there are four types of population fluctuations.

1. Stable: When populations fluctuate slightly above or below the carrying capacity.
2. Irruptive: When a population that is normally stable experiences a large increase in abundance as a result of a temporary increase in the carrying capacity.
3. Irregular: When a population fluctuates for a reason that has not been identified.
4. Cyclical: When a population fluctuates with regular frequency. This includes species that follow predator–prey cycles.

In addition to fluctuations over time, populations can vary across space, especially in heterogeneous landscapes (Tilman and Kareiva 1997). This makes it difficult to establish a baseline population for a given species in the absence of long-term and spatially distributed data. Furthermore, it is often difficult to separate the effects of human activities on species populations from natural fluctuations (Pechmann et al. 1991).

In the absence of natural processes and/or predators, the population size of a species may grow unchecked, potentially until it reaches the carrying capacity of the area—defined as the number of individuals an area can support, given available resources (Stokes 2012). Unnaturally abundant populations may end up exhausting local resources, leading to a population crash—such as elephants in some African protected areas (Whyte 2007)—or conflict with human neighbours. For example, within the town of Banff in Canada, large numbers of elk found refuge from the grey wolves of the national park. Although they are majestic animals, they can also be quite dangerous to humans, especially during the rutting season. After a series of human–wildlife conflict incidents, Parks Canada established a community-based Elk Advisory Committee to develop proposals for addressing the issue. Management actions began in 1999 with the goals of restoring natural ecological processes on lands adjacent to the town and the reduction of elk–human conflicts. Actions included trapping more than 200 habituated elk and relocating them into another mountain valley, an ongoing aversive conditioning program to encourage elk to avoid the town and the restoration of wildlife corridors to increase predation of elk close to town. Results have been encouraging, with fewer elk–human conflicts and improved ecosystem conditions adjacent to the town such as reduced herbivory (White et al. 2007).

The US National Park Service (NPS 2006) developed a policy to address management of population fluctuations, clarifying the desire to rely on natural processes, but stipulating conditions when intervention is merited, including when:

Armed Uganda Wildlife Authority rangers on patrol in Mt Elgon National Park to protect the park against poaching of rare and endangered wildlife and encroachment by neighbouring communities
Source: Stuart Cohen

1. the intervention will not cause unacceptable impacts to the populations of the species or to other components and processes of the ecosystems that support them
2. the management of the population is necessary
   - because the fluctuation is the result of human influences
   - to protect rare species
   - to protect humans and property.

Meta-populations

When managing protected areas for biodiversity, it is important to recognise that some species may exist as meta-populations. A meta-population generally comprises discrete sub-populations. Each sub-population will have its own dynamics (rates of birth, death, immigration and emigration) (Hanski and Simberloff 1997). Meta-populations should not be confused with a single population that is simply patchy in distribution, but has the same dynamics. It is important that managers understand if they are managing a single population or a meta-population of a given species (Chapman et al. 2003). The implication for protected area management is that it is necessary to allow for connectivity among sub-populations or specific management actions for a sub-population.

Population viability

Perhaps the most common target cited when managing for populations in protected areas is that of a 'viable' population. Viability is best understood as the probability of a given species persisting over a defined period. The first population viability analysis (PVA) is credited to Mark Shaffer's 1978 calculation of extinction probability for grizzly bears (*Ursus arctos horribilis*) in Yellowstone National Park (Shaffer 1978). Since then, PVAs have become more sophisticated and complex, incorporating numerous variables that could potentially affect a species' viability (Gilpin and Soulé 1986; Traill et al. 2010), culminating in software that brought PVA to the computers of many park biologists (for example, RAMAS, VORTEX). The use of PVAs for protected area management decisions is, however, not without its controversies (Flather et al. 2011). Large amounts of data are required to perform robust PVAs, especially fieldwork-intensive and species-specific data (Beissinger and McCullough 2002). Furthermore, the results of PVAs typically have wide confidence intervals and are therefore prone to large errors (Flather et al. 2011). Nevertheless, PVAs can provide some insight into management decisions, as long as they are used cautiously, and are useful for determining which variables have the greatest influence on species viability (Akçakaya and Sjögren-Gulve 2000). For example, a study of a mountain zebra in the Gamka Mountain Nature Reserve in South Africa determined that frequent prescribed burning of preferred habitat was one of the most important management actions that could improve the viability of that endangered species (Watson et al. 2005).

Managing threats to protected areas

At a global scale the principal causes of biodiversity loss and species extinction are habitat loss and fragmentation, with other major threats including habitat degradation and pollution, overexploitation, the impact of alien invasive species and, increasingly, climate change. Although there is some evidence that protected area status may give additional protection to natural habitats (Geldmann et al. 2013), many protected areas are still threatened by habitat loss and degradation (Case Study 21.7).

Over the past two decades, the Conservation Measures Partnership has developed a common framework for identifying threats to biological diversity and ecosystem processes (Margoluis and Salafsky 1998; TNC 2000, 2007; Salafsky et al. 2003, 2008; CMP 2013). This framework can be applied to protected area management (Box 21.4 and Table 21.1). When dealing with protected areas, it is important to distinguish stresses (which are often internal to the protected area and may require restoration work) from direct threats (which generally come from outside the protected area). Often at an individual site, or even a system level, protected area

Case Study 21.7 Protected areas and forest loss

Despite the legal status of protected areas, their designation does not in itself guarantee protection of ecosystems. Although protected areas generally reduce deforestation relative to unprotected areas, there may still be land-use change within them (Clark et al. 2008).

An analysis of deforestation in the humid tropics (Hansen et al. 2008) showed that between 2000 and 2005 an estimated 21 million hectares of humid tropical forest were lost globally—a 2 per cent reduction in forest cover. During this period, more than 1.7 million hectares were cleared within protected areas in the humid tropics (0.81 per cent of the forest they contained). Globally, more strictly protected areas (IUCN Categories I–II) had lower rates of humid tropical forest loss (0.53 per cent) than the protected area network as a whole. This has implications for both biodiversity and climate change. Based on the deforestation estimates, the UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) calculated that forest loss in protected areas contributed as much as 990 megatons of carbon dioxide equivalent to global carbon dioxide emissions between 2000 and 2005, or about 3 per cent of total emissions from tropical deforestation (Campbell et al. 2008).

In a systematic review of the effectiveness of protected areas in reducing forest loss and species population declines, Geldmann et al. (2013) concluded that there is good evidence that protected areas have conserved forest habitat. Nevertheless, evidence remains inconclusive about whether protected areas have been effective at maintaining species populations, although more positive than negative results are reported in the literature. Causal connections between management inputs and conservation outcomes in protected areas are rarely evaluated in the literature. Overall, the available evidence suggests that protected areas do deliver positive outcomes for biodiversity, but there remains limited empirical evidence of the conditions under which protected areas succeed or fail to deliver conservation outcomes.

Protected areas are ultimately about managing key features (species, ecosystems, recreational opportunities and heritage values) and safeguarding them from threats. In a world of limited staff and financial resources, protected area managers cannot necessarily take on all of the issues and problems facing these features. Instead, they need to be able to focus their actions and their monitoring efforts on the most important challenges. To this end, it is vital to be able to identify and design realistic strategies to counter threats to specific features in individual protected areas.

managers can only deal with direct threats rather than the underlying root causes. This is especially true when threats to protected areas are driven by national or local policy and social and economic factors over which an individual protected area manager may have little or no influence—for example, government policies on agriculture and transport networks (MacKinnon 2005). On the other hand, direct threats within and immediately adjacent to protected areas can be addressed through management actions—for example, invasive species control, human–wildlife conflict and visitor management.

Conservation ultimately takes place through conservation 'projects' (Salafsky et al. 2008), which range in scale from efforts by a small community to manage their traditional fishing grounds to a global funding program to protect the world's oceans. Building on a review of terms used by different conservation practitioners, Salafsky et al. (2008) and the Conservation Measures Partnership (CMP 2013) have proposed definitions to describe the general components of any given conservation project (Box 21.4). For protected area managers, the project scope is usually defined by the boundaries of the protected area and any surrounding buffer zones (see Chapter 13).

Classification of threats

Table 21.1 illustrates the classification of threats according to the IUCN–Conservation Measures Partnership. The classification is constructed in a hierarchical fashion with three different levels, analogous to families, genera and species in the Linnaean system. The first level is denoted by whole numbers and bold text—for example, **'1. Residential and commercial development'.** The second level is denoted by decimal numbers and roman text—for example, '1.2. Commercial and industrial areas'. The third level is denoted by italic text—for example, '*Manufacturing plants*'. The classification is designed to be comprehensive, consistent and exclusive for the first and second levels, meaning that all possible threats to biodiversity should be able to fit into the system, with each threat assigned to only one category.

Assessment of threat magnitude for protected area management

The final step in developing a systematic approach to threats involves developing a standard way of measuring and comparing threat magnitude. If one is interested in merely assessing a specific threat to a specific conservation target/feature or protected area over time, the obvious measurement is to directly assess and track the size of the threat using the best available quantitative indicator—for example, the number of elephant poaching incidents

Box 21.4 Key definitions for understanding ecosystem threats

- *Biodiversity targets*: The biological entities (species, communities or ecosystems) that a project is trying to conserve (for example, a population of a specific species of fish or a forest ecosystem). Some practitioners also include ecological and evolutionary phenomena and processes as targets (for example, fire regime, seasonal migration, gene flow).
- *Human wellbeing targets*: The components of human welfare affected by the status of biodiversity conservation targets. Examples might include human livelihoods from use of biological resources or spiritual values derived from natural systems.
- *Stresses*: Attributes of a conservation target's ecology that are impaired directly or indirectly by human activities (for example, reduced population size or fragmentation of forest habitat). A stress is not a threat in and of itself, but rather a degraded condition or 'symptom' of the target that results from a direct threat.
- *Direct threats*: The proximate human activities or processes that have caused, are causing or may cause the destruction, degradation and/or impairment of biodiversity targets (for example, unsustainable fishing or logging). Threats can be past (historical), ongoing and/or likely to occur in the future. Natural phenomena may also be regarded as direct threats in some situations.
- *Contributing factors*: The ultimate factors—usually socioeconomic, political, institutional or cultural—that enable or otherwise add to the occurrence or persistence of proximate direct threats (for example, government agricultural policies or market forces that increase the expansion of agricultural land or the overexploitation of resources such as fisheries).
- *Conservation actions*: Interventions undertaken by project staff or partners designed to reach the project's objectives and ultimate conservation goals (for example, reintroducing an endangered species or setting up a protected area). Actions can be applied to contributing factors, direct threats or directly to the targets themselves.
- *Project teams*: The groups of people involved in designing, implementing, managing and monitoring projects (for example, a partnership between a local non-governmental organisation or a community and the staff of a national park).

or the percentage of buffer zone forest that is lost to an encroaching agricultural frontier. If, however, one is interested in comparing combined threat levels with different targets/features or with different protected areas across time and space, a more complex methodology is required.

Assessments of threat magnitude are important for a number of key tasks undertaken by protected area managers. In particular, without common measurements of threats, it is difficult for protected area managers to:

- set priorities: to compare protected areas within an overall system and set priorities for resource investment and to plan which of these prioritised places should be tackled immediately and which can be deferred until later
- develop effective strategies: to select which threats to address within a given protected area and to compare the potential leverage obtained by using different strategies and decide which to use
- measure conservation status and effectiveness: to determine and compare changes in the status of threats at one location over time and to determine the relative effectiveness of different conservation actions in relation to threat-based objectives
- learn from experience: to compare one manager's experiences with those of others, which is the foundation of any kind of systematic learning about how to effectively and cost-effectively counter each type of threat.

In the late 1990s and early 2000s, a number of conservation organisations began to develop systematic methods for assessing threat magnitude in a more standardised fashion (for example, Salafsky and Margoluis 1999; TNC 2000; Ervin 2002; WCS 2002). In the mid 2000s, a CMP Working Group reviewed these different systems and used them to create a standard methodology for rating threats that became the basis for the 'simple threat rating' methodology in Miradi software (Miradi 2007).

Table 21.1 Threat categories and some examples of the current unified IUCN–Conservation Measures Partnership classification of conservation threats

Threats by level of classification	Definition
1. Residential and commercial development	Human settlements or other non-agricultural land uses with a substantial footprint
1.1. Housing and urban areas *Urban areas, suburbs, villages, vacation homes, shopping areas, offices, schools, and so on*	Human cities, towns and settlements including non-housing development typically integrated with housing
2. Agriculture and aquaculture	Threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture and aquaculture
2.4. Marine and freshwater aquaculture *Shrimp or fin-fish aquaculture, fish ponds on farms, hatchery salmon, seeded shellfish beds, artificial algal beds*	Aquatic animals raised in one location on farmed or non-local resources; also hatchery fish allowed to roam in the wild
3. Energy production and mining	Threats from production of non-biological resources
3.1. Oil and gas drilling *Oil wells, deep sea natural gas drilling*	Exploring for, developing and producing petroleum and other liquid hydrocarbons
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 *Highways, secondary roads, logging roads, bridges and causeways, roadkill, fencing associated with roads, railroads*	Surface transport on roadways and dedicated tracks
5. Biological resource use	Threats from consumptive use of 'wild' biological resources including deliberate and unintentional harvesting effects; also persecution or control of specific species
5.1. Hunting and collecting terrestrial animals *Bushmeat hunting, trophy hunting, fur trapping, insect collecting, honey or bird-nest hunting, predator control, pest control, persecution*	Killing or trapping terrestrial wild animals or animal products for commercial, recreational, subsistence, research or cultural purposes, or for control/persecution reasons; includes accidental mortality/bycatch
6. Human intrusions and disturbance	Threats from human activities that alter, destroy or disturb habitats and species associated with non-consumptive uses of biological resources
6.1. Recreational activities *Off-road vehicles, motorboats, jet skis, snowmobiles, ultralight aircraft, dive boats, whale watching, mountain bikes, hikers, birdwatchers, skiers, and so on*	People spending time in nature or travelling in vehicles outside established transport corridors, usually for recreational reasons
7. Natural system modifications	Threats from actions that convert or degrade habitat in the service of 'managing' natural or semi-natural systems, often to improve human welfare
7.1. Fire and fire suppression *Fire suppression to protect homes, inappropriate fire management, escaped agricultural fires, arson, campfires, fires for hunting*	Suppression or increase in fire frequency and/or intensity beyond its natural range of variation
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 *Feral cattle, household pets, zebra mussels, Dutch elm disease or chestnut blight, Miconia tree, introduction of species for biocontrol, Chytrid fungus affecting amphibians outside Africa*	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

Threats by level of classification	Definition
8.2. Problematic native species *Overabundant native deer, overabundant algae due to loss of native grazing fish, native plants that hybridise with other plants, plague affecting rodents*	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
9. Pollution	Threats from introduction of exotic and/or excess materials or energy from point and non-point sources
9.2. Industrial and military effluent *Toxic chemicals from factories, illegal dumping of chemicals, mine tailings, arsenic from goldmining, leakage from fuel tanks, PCBs in river sediments*	Waterborne pollutants from industrial and military sources including mining, energy production and other resource extraction industries, including nutrients, toxic chemicals and/or sediments
10. Geological events	Threats from catastrophic geological events
10.2. Earthquakes/tsunamis	Earthquakes and associated events
11. Climate change and severe weather	Long-term climatic changes that may be linked to global warming and other severe climatic or weather events outside the natural range of variation that could wipe out a vulnerable species or habitat
11.1. Habitat shifting and alteration *Sea-level rise, desertification, tundra thawing, coral bleaching*	Major changes in habitat composition and location
11.2. Droughts *Severe lack of rain, loss of surface water sources*	Periods in which rainfall falls below the normal range of variation

Source: IUCN-CMP classification of direct threats to biodiversity (Version 1.1) (CMP 2013)

The Miradi simple threat rating method

The *Miradi Adaptive Management Software* (Miradi 2007) is designed to be applied to assess the impact of a specific threat on a given conservation target, using a combination of *scope* (area) and *severity* (intensity) that, when combined, provides an indication of the *magnitude* of the threat. Miradi uses specific four-point rating scales for each criterion (very high, high, medium and low) that, where possible, are linked to specific percentages. The thresholds between criteria are designed to represent both ecologically and practically meaningful breakpoints between the categories. The Miradi threat assessment system should generally apply to protected areas of all types and sizes; however, the system may need to be adapted to handle assessments of non-conservation features as well as the stresses posed by threats such as climate change. Combining the scope and severity ratings gives an overall threat magnitude rating (Figure 21.5). It is also helpful to consider irreversibility (the degree to which the *effects of a threat* can be reversed) in combination with magnitude in order to compare or prioritise threats for management action (Figure 21.6). The effects of one threat on multiple targets or multiple threats on one target can be combined or rolled up using various rule-based systems (for more details, see Miradi 2007). This produces a final threat summary table (Figure 21.7).

The biodiversity conservation community has made great progress in the past few years in developing standardised methods for defining and measuring threats to species and ecosystems. There is great potential for using these tools in protected area management, but modifications will be necessary to optimise these methods to the specific needs faced by protected area managers.

Monitoring and assessment of ecological condition in protected areas

In this section, we refer to monitoring as both inventory and monitoring. Inventory is the essential first step and monitoring is generally repeated measures of the first inventory or parts of it. Very few protected areas are doing a good job of ecological monitoring even though it is essential to understand if the protected area is being successful in conserving nature and meeting its stated conservation objectives. Moreover, an investment in monitoring avoids surprises and irresolvable problems in the future. Building monitoring into park management should be considered a fundamental part of park management. In the long term, it can save money by preventing costly restoration projects (also see Chapter 28).

		SCOPE			
		Very High	High	Medium	Low
SEVERITY	High	High	High	Medium	Low
	Medium	Medium	Medium	Medium	Low
	Low	Low	Low	Low	Low

Figure 21.5 Combined threat and severity ratings to determine threat magnitude

Source: Miradi (2007)

		IRREVERSIBILITY			
		Very High	High	Medium	Low
MAGNITUDE	Very High	Very High	Very High	Very High	High
	High	Very High	High	High	Medium
	Medium	High	Medium	Medium	Low
	Low	Medium	Low	Low	Low

Figure 21.6 Combined assessments of threat irreversibility and magnitude to prioritise management actions

Source: Miradi (2007)

Threats vs Values	Asian Elephant	Forest Ecosystem	Functional Corridor	Grasslands of Terai	One-horned Rhino	Tiger	Summary Threat Rating
Cattle Grazing		High	Low	High			High
Encroachment		Very High	Very High	High			Very High
Fuelwood Collection		High	Medium				Medium
Illegal Wildlife Killing					Very High	Very High	Very High
Logging		Low	Low				Low
Overexploitation of Non-timber Products		Low	Low	Low			Low
Summary Target Rating	None	High	High	High	High	High	Very High

Figure 21.7 Threat summary rating for an example ecosystem

Source: Miradi (2007)

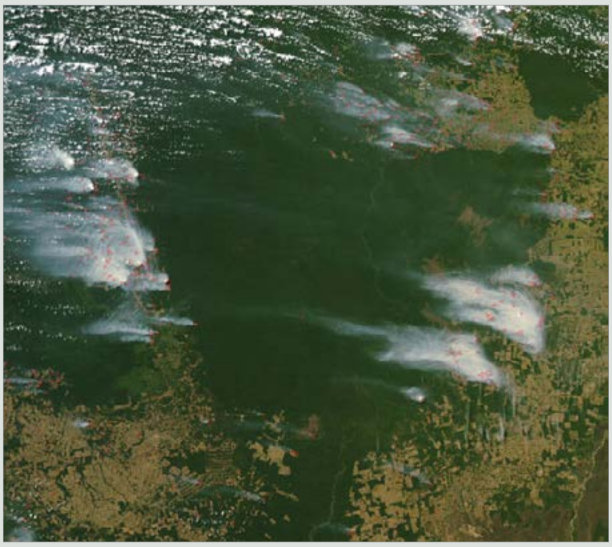
Case Study 21.8 Globally available wildfire monitoring

Wildfires and fires for slash-and-burn agriculture are two of the most important causes of deforestation in Madagascar. The use of satellite remote sensing to detect fires can enable managers of protected areas and other forests to respond quickly to illegal fires. NASA's Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument on board the *Aqua* and *Terra* satellites provides thermal and mid-infrared data four times daily, allowing the detection of fires. The data, however, require interpretation and analysis, which makes their use by field-based land managers difficult. To develop a user-friendly product, Conservation International, the University of Maryland and the Madagascar Forestry Department developed a fire alert system that provides daily email alerts to users based on their geographical area of interest.

In Madagascar, the fire alerts provide protected area and forestry staff with timely and accurate information of illegal fires and encroachment activity. This allows field managers to react rapidly to encroachment but it also provides valuable monitoring statistics for tracking the fire threat at different sites. The fire data can also be used to improve understanding of patterns of threats to forests at the national scale, and have been used to inform the development of the national strategy for mitigating climate change through the Reducing Emissions from Deforestation and Forest Degradation (REDD).

Initially, in 2002, the fire alert system sent registered users a simple list of detected fires with their exact position. A more advanced system developed in 2007 allows users to define the frequency of alerts and receive maps tailored to their specific areas of interest—for example, administrative regions, individual national parks and fires within natural forests. The system, known as Firecast, has since been expanded to include Bolivia, Peru and Indonesia, and now also includes fire-risk prediction alerts. Firecast is free and accessible (Firecast 2014).

— James Mackinnon



Fires near Xingu Indigenous Park, Brazil

Source: Jacques Descloitres, MODIS Rapid Response Team, NASA-Goddard Space Flight Center, <rapidfire.sci.gsfc.nasa.gov>

Even if there are no monitoring systems currently in place, most protected areas can find some useful data to assess ecological condition. Visitors, staff, scientists and indigenous and local peoples all make observations about the land and waters of protected areas on a regular basis. Global sensor systems, including satellites and weather stations, continually make observations and, increasingly, there is free satellite information available (Case Study 21.8). The initial step in developing a monitoring system for biological diversity and ecosystem processes is to catalogue and organise these existing data in order to provide the best available evidence for making management decisions.

There are two key monitoring questions for protected areas. This section will help with understanding and developing answers to these questions.

1. What is the ecological condition: do we need to take management action?
2. Have management actions been effective?

Managers will want to have the best possible information for answering these questions. This is indeed a challenge, as both these questions are complex. As a starting point, do not be overly concerned about the amount of money and expertise available for observing the protected area. Some information is better than none, although management decisions must be based on what is known and unknown. Even simple, well-organised information is more persuasive than the disconnected and poorly documented kind. The best practice is to work with what is available and build partnerships for long-term monitoring to supplement monitoring done by protected area staff.

This chapter will not provide a full guide for all the elements of designing a monitoring program, and collecting and analysing the data. Readers are referred to guidebooks on the subject, such as Lindenmeyer and Likens (2010) and Gitzen (2013). In addition, there are agency websites that contain details on monitoring and monitoring protocols, such as the US National Park Service Inventory and Monitoring Program (NPS 2014). Finally, there are a large number of taxa-specific and ecosystem-specific guides available online. This section covers basic considerations in thinking about the design and implementation of a biodiversity and ecosystem function monitoring program for protected areas.

What to observe?

Condition monitoring

To answer the question 'what is the ecological condition: do we need to take management action', the first requirement is to know what should be measured to assess ecological condition. It makes sense to begin by assessing the species and processes referred to in the protected area's establishment document or management plans. Species that are immediately identified with the site and the ecological processes that maintain its characteristic look (for example, fire on savannah) are likely to be the most important place to start (see the 'Assessing protected area condition: Ecological integrity' section above). The protected area agency's policy and legislation may also provide guidance on selecting specific species and processes to monitor—for example, rare species and key conservation targets. It is important to maintain a systematic and unbiased approach to monitoring to avoid researcher bias. Protected area managers should use a structured framework to select indicators. In most cases, a set of indicators should be selected for each of the major ecosystems in a protected area—that is, forests, wetlands, grasslands, and so on. An example of a template for ecological monitoring used by Parks Canada, which includes biodiversity, ecosystem function and known stressors as components of a monitoring framework, is illustrated (Table 21.2).

After a candidate list of species, functions and threats has been selected, managers should give some consideration to the cost in time and money to measure these different aspects. There are often ways to do things more cheaply to achieve some useful results. For example, precise population counts might be replaced with a simpler index of abundance from dung counts. Ground-stationed wildlife cameras can produce useful information on species presence and distribution (O'Brien 2014). There is an online *Handbook for Wildlife Monitoring Using Camera Traps* (Ancrenaz et al. 2012). The spatial extent of a disturbance can be estimated using a global positioning system (GPS) on the ground rather than from an airplane.

Effectiveness monitoring

For protected areas that have active management and restoration programs, it is important to monitor whether or not the ecological goals of management actions have been achieved. Choosing what to measure is generally straightforward since efforts are usually targeted to certain species or habitat types and desired trends—for example, more abundant native species, less abundant invasive species or disturbances similar to those under low-density human habitation.

Who can observe?

Who can actually do ecological monitoring is not clear-cut. Fundamentally, ecological monitoring is a science-based activity. Monitoring programs are ideally designed by people with a scientific background, properly field tested and peer reviewed. Once a clear method or monitoring protocol is designed, however, many people can be trained to collect monitoring information. For example, rangers and wardens are ideal candidates because they regularly patrol and observe large parts of protected areas. Increasingly, citizen scientists are being trained to provide monitoring data, even using devices such as smart phones.

The opportunity to include visitors and indigenous and local people in monitoring protected areas should be given some serious consideration. Engaging these people

Table 21.2 Example of a selection template for ecological integrity monitoring measures

Biodiversity	Ecosystem functions	Stressors
Species lists • change in species richness • numbers and extent of exotics **Population dynamics** • mortality/natality rates of indicator species • immigration/emigration of indicator species • population viability of indicator species **Trophic structure** • faunal size class distribution • predation levels	**Succession/retrogression** • disturbance frequencies and size (fire, insects, flooding) • vegetation age class distributions **Productivity** • remote or by site **Decomposition** • by site **Nutrient retention** • Calcium and nitrogen by site or watershed	**Land-use patterns** • land-use maps, road densities, population densities **Habitat fragmentation** • patch size, inter-patch distance, forest interior **Pollutants** • sewage, petrochemicals, and so on • long-range transport of toxins **Climate** • weather data • frequency of extreme events **Other** • park-specific issues

Source: Woodley (1993)

Case Study 21.9 Monitoring using citizens and traditional knowledge

Project Noah (2014) is an innovative website that records the location and date of wildlife photographs taken by citizen scientists. The photographs are taken by interested people and there is a set of instructions to upload images of a certain kind. For example, The Birds of Sub-Saharan Africa has 101 participants and more than 1500 sightings of birds. It is easy to become a member and upload images from a smart phone. Photos can be constrained to a weekend bioblitz in a protected area or focused on topics such as pollination, phenology or invasive species.

Inuit Qaujimajatuqangit, Canada

Inuit Qaujimajatuqangit or IQ is the hard-won wisdom of the indigenous people of the Nunavut Territory of Canada—survivors in a harsh northern landscape. This local ecological knowledge is a key component of local governance, especially in the management of natural resources. Gilchrist et al. (2005) examined the effectiveness of IQ, especially with regards to recent population and distribution trends for four species of migratory birds. For two of the species examined, local knowledge identified population shifts that were previously unknown to Western science. In general, the degree of contact with the species was an important factor in determining the quality of observations. In one case, the species' distribution was poorly understood by local hunters despite seasonal harvests. Thus, like any source of information, there must be scrutiny of reliability.

and respecting their insights will benefit a protected area in ways that go beyond the preparation of standard visitor information. Often these are the same people who will need to be convinced of the need for action in the protected area. Including people early in the process builds trust and understanding. The feelings and spiritual significance attached to observations by visitors and indigenous and local people are critical, although it may be difficult to include these observations in a common framework with those of staff and visiting scientists (Case Study 21.9).

A monitoring program has to be designed around the needs and unique situation of the individual protected area. In many cases, scientists will be situated nearby in universities, government agencies or non-governmental organisations (NGOs) and may be interested in conducting long-term monitoring studies. In other cases, a protected area will have trained staff. In many situations, however, and especially where protected areas lack their own research staff, local citizens and traditional land managers can provide useful additional understanding of their ecosystems. Perhaps the best way to think about who should be involved in monitoring is to see the program as a partnership, which can evolve over time. The challenge for a protected area manager is to ensure there are enough people, with enough training, to be able to report on the ecological conditions.

Monitoring protocols

Monitoring of any ecological entity will require the development of a monitoring protocol—that is, a set of written conditions that specifies the how, what, when, where and why of monitoring. It includes the following.

1. What is the monitoring question being asked? For example, what is the population of cranes in the protected area and is that population changing?
2. What is the ecological variable to be measured and how does it relate to the monitoring question? For example, a useful way to count cranes might be to conduct spring crane counts when the birds arrive for breeding, as they are very easy to see and count then.
3. What certainty is needed to detect change? This is both a management question and a statistical question. For example, if cranes are counted for two days each spring, it may only be possible to know the population with a variation of plus or minus 20 per cent. Therefore, depending on sampling frequency, the manager would not be able to detect year-to-year changes unless they were greater than 20 per cent. If the crane is a threatened species, however, the manager may wish to know if the population is changing with a certainty greater than 20 per cent. This analysis of the ability to detect change is called a 'power analysis'. There are guides to this in most statistical texts (for example, Ellis 2010), online or from a statistician. There is almost always a trade-off between the level of certainty to detect change and the cost of a monitoring program.

Field methods

A clear set of methods should be written to detect change. Following the crane example, the methods should specify all the details required for a spring count, including where to go, when to count, whether to count juveniles separately from adults, and so on. This methods section should be very specific so that methods can be easily repeated by different observers.

Data collection and storage

This part of a protocol includes how the data will be collected, how data will be stored and what quality controls are necessary. For example, there may be a field datasheet for crane counts with all the metadata

(observer name, date, location, and so on) as well as the actual count data. The datasheet will then go into a file storage (perhaps copied for backup) and may be entered into a computer spreadsheet or database. A good protocol would include quality-control rules for ensuring that observations are transferred correctly from the field worksheet to the computer. Quality control might also include an independent person checking the numbers.

Data analysis

A protocol should specify how a set of measures will be analysed, including the statistical methods, and ways to determine the significance of the finding. For the crane example, if 10 years of data showed there was 95 per cent confidence that the cranes were declining at a rate of 2 per cent per year, would that result in a management action?

Other requirements

The final elements of a protocol should ensure that all other factors for success are considered. This includes training, specialised equipment, research permits and communications. Thus, all field staff engaged in a crane count might need training to successfully identify males from females or juveniles from adults.

Interpreting monitoring results: Some general considerations

Analysing and interpreting data collected from a monitoring program are perhaps the most difficult parts of monitoring biodiversity and ecosystem processes. It has become even more difficult in the current context of climate change and widespread exposure to invasive species.

There is rarely perfect clarity for the level of a chosen measure in a healthy ecosystem. Nonetheless, the following steps will help in making sense of observations:

- ask clear monitoring questions
- make sure that monitoring design can answer these questions
- choose indicators that are simple, repeatable and that will be interpreted in the same way by different observers
- summarise the answers to these monitoring questions and recommend whether action should be taken.

There are some basic questions that can be asked about the results from monitoring a species characteristic or ecological process.

Whooping cranes (*Grus americana*) are an endangered species with only a small population remaining in the wild, USA

Source: Alison Woodley

1. Is it high or low within the range of possible values?
2. Is it changing? If it is changing, is that change in the desired direction (for example, an increase in the abundance of target species or a reduction in invasive species)? Often monitoring will focus on trends, rather than on absolute numbers.
3. Are the results affected by known conservation threats (Table 21.1)?
4. Is the result affected by interactions with other species or processes?

To answer these questions managers need a monitoring design. Any monitoring program makes a number of assumptions about the area of the reserve that will be affected, the changes that can be detected and levels of certainty. A statistician or scientist can help to name these assumptions and strengthen the design. Some guidance is provided on the minimum number of observations needed to answer certain questions (Table 21.3).

Monitoring is only useful if results are analysed and evaluated and built into follow-up management action. Table 21.3 recommends minimum sample sizes for detecting fairly obvious differences in an ecosystem. Each design in the table assumes a 20 per cent chance of a false-positive result and a 20 per cent chance of a false-negative result.

Analysing data to answer the question ‘have management actions been effective’ is generally easier to approach than condition monitoring. Instead of wondering what an ecosystem ‘should’ do, the manager is asking whether it did what was expected after a specific management treatment. It is often important to frame the effectiveness question in the time frame of practical management, regardless of the lifespan of the species involved or the speed of the processes, because project

Long-term monitoring exclosures are used by park managers to determine the impacts of introduced species such as wild horses in the Victorian Alpine National Park, Australian Alps
Source: Ian Pulsford

funding for protected area management is usually short term and thus requires short-term measures of success. Because ecosystems have response time lags, effectiveness monitoring should, however, also have longer-term measures linked to the condition-monitoring program for the protected area.

The targets for effectiveness monitoring can be clear expectations of impacts, such as the percentage of area successfully treated or species population size attained. These expected targets should represent a response by the ecosystem rather than a measure of the effort applied. Meeting these targets generally requires less attention to the statistical assumptions that are so important in condition monitoring.

Long-term recording of monitoring observations

Monitoring information should be stored in a location where it can be easily accessed, is safe in the long term and is properly documented. Most protected area organisations would benefit from improved data management. Many observations are lost in the long term or do not have adequate metadata. There are formal metadata standards that describe what needs to go along with the data collected, including how it was collected, who collected it, exact methods used, locations, and so on. Metadata are as important as the datum itself. For biodiversity data, a common metadata standard is the 'Darwin Core' and this is available online (Wieczorek et al. 2012). The Darwin Core is simply a checklist of things that should be in metadata such as date, species name and geographic coordinates. There is far too much data that is not useful simply because it is missing metadata.

Repeated observations by protected area managers and indigenous people can be translated into data management standards that strengthen understanding of the protected area over time. The keys to monitoring include: 1) clear monitoring protocols that maintain a consistent measurement technique across time, locations and observers; and 2) accessible data storage that moves the observations into the public realm. Finding a suitable repository is important (Box 21.5).

Table 21.3 General guideline on the number of observations required to detect trends

What do you want to detect?	Analysis and effect size	Number of samples
An unusual year	One sample t-test; 1 standard deviation difference between unusual year and previous average	7 annual observations
A trend over time	One-sample z-test; a strong correlation coefficient > 0.7	9 independent observations over a period
A change in the average value	Paired t-test; an average difference between repeated measures on the same sites or individuals that amount to half the standard deviation in the data	19 observations repeated in each of two years
A difference between two treatments	Two sample t-tests; a difference of half the standard deviation in the data between the average values of two treatments	37 observations in each treatment

Source: Stephen McCanny

Posting monitoring data along with its protocol is not the end of conserving long-term data. Assuring the long-term (50–100 years) accessibility of monitoring data will require awareness of changes in electronic media. Electronic information, like paper files, must be curated. It faces the additional risk of being eliminated through faulty backup procedures. The best guarantee that monitoring data will survive is to ensure they receive regular use and updates by conservation organisations.

Box 21.5 Finding a repository for storing monitoring information

Many governments or NGOs may already have an open data catalogue where data can be posted (for example, <datacatalogs.org>). There may also be an internal website for posting information for staff access.

There are also a number of repositories specifically for protected areas and conservation. The Global Biodiversity Information Facility (GBIF) is an international open data infrastructure for biodiversity information. It allows anyone, anywhere, to access data about all types of life on Earth, shared across national boundaries via the Internet.

Protected Planet is a dynamic website (<www.protectedplanet.net>) hosted by the UNEP-WCMC, which seeks to describe the world's protected areas. The Open Parks Network is a knowledge pipeline for park professionals, which hosts digitised archives and hard-to-find information (OPM 2014).

Conclusion

Managing protected areas is an increasingly complex job that requires a good understanding of the ecology of the place, as well as some fundamentals about how ecosystems work. Below is a summary of the key messages from this chapter for protected area managers.

1. Protected areas, as ecosystems, have both biodiversity and supporting ecosystem functions. The two are connected and affect each other. It is not possible to manage just for a species or an ecosystem type, without also considering the ecological processes that support them.
2. Monitoring ecosystem condition and management actions is a fundamental part of protected area management. Monitoring systems should be part of the overall management framework of a protected area. A monitoring system needs to be based on a fundamental understanding of ecosystem structure and function.
3. The applied science of conservation biology provides a range of well-developed tools and approaches for the management of biodiversity at all scales, from genetic to ecological community. Population management approaches are the best developed and include detailed considerations for managing genetic diversity, meta-populations and viability.
4. Management of ecological functions is possible and necessary in many protected areas. A good example is the use of fire in fire-adapted ecosystems.
5. Much protected area management is focused on the management of ecological threats. This chapter presents a formal, structured approach to defining, assessing and rating ecological threats in protected areas.

The science behind applying management to biodiversity and ecosystem function is large and growing. This chapter aims to provide an overview of the key principles and understandings but cannot cover all areas. Protected area managers should take advantage of the volunteer expertise within the IUCN commissions, including the World Commission on Protected Areas, to help solve protected area management challenges.

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