

14

Protected Areas

Goals, Limitations, and Design

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All we have to decide is what to do with the time that is given us.

J. R. R. Tolkien, 1954

The increasing pressures exerted on the environment by humans make preservation of natural areas crucial for the persistence of biological diversity (McNeely 1994; Groombridge and Jenkins 2002). Protected areas are one of the most effective tools available for conserving biodiversity. While protected areas can be degraded by external pressures, the majority of terrestrial protected areas are successful at stopping deforestation and mitigating the damaging effects of logging, hunting, fire, and grazing (Bruner et al. 2001). **Marine protected areas (MPAs)** often have bans on fishing or may require actions that reduce pollution. Therefore, while dedicating protected areas is only one of many actions we can take to conserve biodiversity, it can abate some of the key threats: habitat degradation, overexploitation, and to a lesser extent, pollution and nonnative species invasion. They form the foundation on which many of our conservation efforts are based.

Terrestrial and marine protected areas around the world not only assist to safeguard biodiversity, but often provide other benefits, such as protecting water supplies, providing flood protection, protecting cultural values, and sustaining the livelihoods of indigenous groups. Protected areas also provide an increasingly urbanized society with much-needed contact with nature.

Today, in regions of particularly intense human settlement, protected areas often contain the only remaining examples of particular habitat types and species populations. For some species restricted to protected areas, such as the northern hairy-nosed wombat (*Lasiornhinus krefftii*) which occurs only in Epping Forest National Park of Australia (Woolnough and Johnson 2000), avoiding extinction is entirely dependent upon the continued protection of its habitat. Other species with large area requirements, such as the elephants of east Africa, may not be afforded adequate protection by one protected area alone. Protecting these species may require a system of protected areas linked by corridors that allow movement from one area to another.

(A)



(B)



Figure 14.1 Many of the large, attractive natural reserves in the United States, such as (A) Grand Canyon and (B) Yosemite were created as geological attractions and for their aesthetic appeal. Consequently, they may not be especially effective for biodiversity conservation. (A, photograph by G. K. Meffe; B, © J. Hughes/Visuals Unlimited.)

The concept of setting aside areas for the preservation of natural values is not a recent phenomenon. Historical examples include the sacred groves of Asia and Africa and the indirect protection of biodiversity afforded by royal hunting forests (Wright and Mattson 1996; Chandrashekara and Sankar 1998). More recently we have moved to more formal establishment of protected areas. The first national protected areas were Yosemite and Yellowstone National Parks in North America, designated in 1864 and 1872 respectively, with the third being Royal National Park near Sydney, Australia, in 1879, followed by Kruger National Park in South Africa in 1892 (Spellberg 1994). Many of the earliest national parks in the U.S. were established primarily to preserve their dramatic landscapes (Figure 14.1).

The establishment of protected areas has tended to be in response to the loss of natural areas in which people have a vested interest. Those who called for the first national parks in America had witnessed a loss of wild places important to them (Nash 1990; Pimm et al. 1995). Hunters in the U.S. were among the first to favor federal land protection as many of them came to understand the crucial role of wildlife refuges and national parks in maintaining their sport. Although hunting was off-limits in these areas, it was here that populations of game animals were sustained (Nash 1990). Contemporary “no take” MPAs play a similar role. By protecting breeding and spawning grounds, they help safeguard fish populations that are caught outside of protected areas (Gerber et al. 2003).

The establishment of protected areas is now a vital legislative component of most national and regional strategies to counter biodiversity loss. In addition, protected area establishment is a requirement for many international environmental agreements and conventions, including the Convention on Biological Diversity (CBD) (Box 14.1), the Convention on the Conservation of Migratory Species of Wild Animals, the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), the Convention for the Protection of the World Cultural and Natural Heritage, and the Convention on Wetlands of International Importance.

This chapter focuses on the functions, design, and limitations of protected areas and the process of reserve system planning. Throughout this chapter, we use the term **protected area** to denote any area of land or sea managed for the persistence of biodiversity and other natural processes in situ, through constraints on incompatible land uses. The term **reserve system** describes a system of protected areas.

The Current State of Protected Areas

The number of protected areas increased rapidly worldwide beginning in the early 1960s (Chape et al. 2004; Figure 14.2). Over 80% of the world’s protected areas have been established since the First World Parks Congress, held in 1962. In total, there are 104,791 protected areas covering approximately 18.38 million km² on land and 1.89 million km² at sea worldwide (see Plate 5). The total

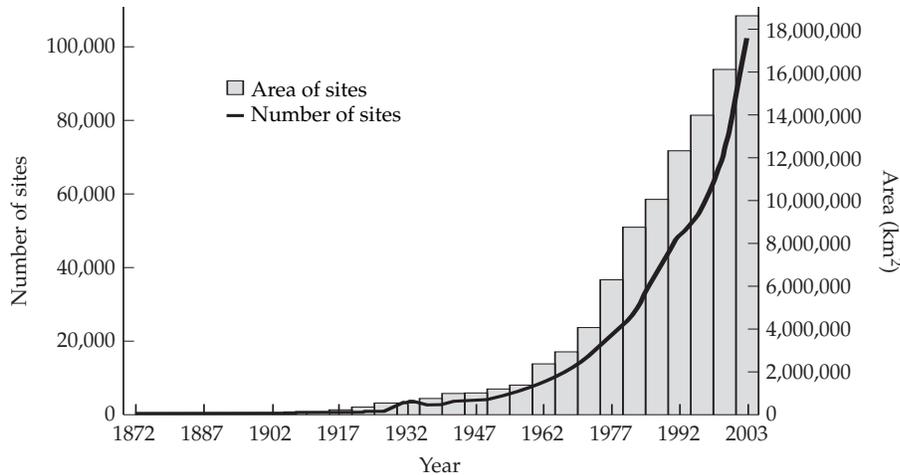


Figure 14.2 Cumulative growth in protected areas from 1872–2003. Number of sites includes both terrestrial and marine reserves, but area of sites includes only terrestrial reserves. (Modified from Chape et al. 2003.)

coverage of protected areas has more than doubled over the last decade to approximately 12.65% of Earth's land surface (Chape et al. 2003). Data on the distribution and status of protected areas are maintained in a freely accessible database by a consortium of organizations (World Database on Protected Areas Consortium 2004).

Types of Protected Areas

Protected areas fall under several different categories and each is accorded a different level of protection. Importantly, these include not only protection in strictly protected areas, but also in areas subject to a variety of man-

agement arrangements that attempt to balance competing uses (land or marine) with biodiversity conservation objectives. The definition of a protected area adopted by the IUCN is, "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means."

Protected areas vary in management intent from strict protection to sustainable extraction of natural resources. The IUCN has defined six protected area management categories, based on the primary management objective, which are summarized in Table 14.1, and reviewed next with some examples.

BOX 14.1 Convention on Biological Diversity

The importance of in situ conservation was highlighted in the United Nations Convention on Biological Diversity—a key document to arise from the Rio de Janeiro Earth Summit in 1992—where it is noted that "the fundamental requirement for the conservation of biological diversity is the in situ conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings." With regard to in situ conservation, Article 8 of the Convention on Biological Diversity states that each contracting party must as far as possible and as appropriate:

1. Establish a system of protected areas or areas where special measures need to be taken to conserve biological diversity.
2. Develop, where necessary, guidelines for the selection, establishment and management of protected areas or areas where special measures need to be taken to conserve biological diversity.
3. Regulate or manage biological resources important for the conservation of biological diversity, whether within or outside protected areas, with a view to ensuring their conservation and sustainable use.
4. Promote the protection of ecosystems, natural habitats, and the maintenance of viable populations of species in natural surroundings.
5. Promote environmentally sound and sustainable development in areas adjacent to protected areas with a view to furthering protection of these areas.
6. Rehabilitate and restore degraded ecosystems and promote the recovery of threatened species (among other things) through the development and implementation of plans or other management strategies.
7. Endeavor to provide the conditions needed for compatibility between present uses and the conservation of biological diversity and the sustainable use of its components.

TABLE 14.1 *IUCN Protected Area Management Categories*

Category Ia	<p>Strict nature reserve: Protected area managed mainly for scientific research.</p> <p>An area of land and/or sea possessing some outstanding or representative ecosystems, geological, or physiological features and/or species; available primarily for scientific research and/or environmental monitoring.</p>
Category Ib	<p>Wilderness area: Protected area managed mainly for wilderness protection.</p> <p>A large area of unmodified or slightly modified land, and/or sea, retaining its natural character and influence, without permanent or significant habitation, which is protected and managed so as to preserve its natural condition.</p>
Category II	<p>National park: Protected area managed mainly for ecosystem protection and recreation.</p> <p>A natural area of land and/or sea, designated to protect the ecological integrity of one or more ecosystems for present and future generations, exclude exploitation or occupation inimical to the purposes of designation of the area, and provide a foundation for spiritual, scientific, educational, recreational, and visitor opportunities, all of which must be environmentally and culturally compatible.</p>
Category III	<p>Natural monument: Protected area managed mainly for conservation of specific natural features.</p> <p>An area containing one or more specific natural, or natural/cultural feature that is of outstanding or unique value because of its inherent rarity, representative or aesthetic qualities, or cultural significance.</p>
Category IV	<p>Habitat/species management area: Protected area managed mainly for conservation through management intervention.</p> <p>An area of land and/or sea subject to active intervention for management purposes to ensure the maintenance of habitats and/or to meet the requirements of specific species.</p>
Category V	<p>Protected landscape/seascape: Protected area managed mainly for landscape/seascape conservation and recreation.</p> <p>An area of land (with coast and sea as appropriate) where the interaction of people and nature over time has produced an area of distinct character with significant aesthetic, ecological and/or cultural value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance and evolution of such an area.</p>
Category VI	<p>Managed resource protected area: Protected area managed mainly for the sustainable use of natural ecosystems.</p> <p>An area containing predominantly unmodified natural systems, managed to ensure long term protection and maintenance of biological diversity, at the same time providing a sustainable flow of natural products and services to meet community needs.</p>

Source: IUCN 1994.

Strict nature reserves and wilderness areas (Category I)

The primary purpose of Category I protected areas is to protect biodiversity and maintain evolutionary and ecosystem processes, as well as ecological services. Category I areas also are managed for scientific research and environmental monitoring. Recreation is excluded so that research and monitoring can be undertaken in minimally-disturbed sites. Selection of these areas is based not only on their representative character, but on the adequacy of their size for protecting their values of importance. The areas should be significantly free of direct human intervention, although the objectives of wilderness areas may be to allow indigenous people to maintain their lifestyle and traditional forms of ecosystem management. The establishment of Category I protected areas is difficult because they exclude mechanized forms of transportation and extractive use, and limit access.

National parks (Category II)

National parks are protected areas managed mainly for ecosystem protection and human enjoyment or recreation. Direct exploitation is excluded and parks are designated to provide for environmental preservation as well as spiritual, scientific, educational, and recreational opportunities that are environmentally and culturally compatible. Achieving this dual mandate of providing both ecosystem protection and opportunities for recreation can be complicated. For example, in the U.S. a controversial issue is whether the recreational use of snowmobiles should be allowed in Yellowstone National Park's backcountry in wintertime. It has been argued that their use compromises the Park's mandate for environmental preservation due to their associated noise and exhaust pollution.

An example of a Category II protected area is the 32,000-ha Tubbataha Reef Marine Park of the Philip-

piners. This park is comprised of two atolls and protects outstanding marine resources, which are considered to be of great importance for sustaining the region's fisheries, and also support an active recreational diving industry. Case Study 14.1 by Carlos Fernández-Delgado highlights the Doñana National Park of Spain, which is a globally important stopover for migrant bird species.

Natural monuments (Category III)

Category III protected areas are managed for the conservation of specific natural or cultural features and thus are generally more limited in size and scope than Category I or II protected areas. Natural monuments might protect natural features such as a waterfall, cave, or dune, as well as culturally significant features such as ancient archaeological sites. Natural Monuments may also protect significant biological features, such as the Giant Sequoia National Monument in the U.S.

Habitat/species management area (Category IV)

Category IV protected areas are established for conservation purposes but require management intervention to ensure their biodiversity values are sustained. Scientific research and environmental monitoring are often the primary activities undertaken in these areas. The Baiyer River Sanctuary in Papua New Guinea, for example, provides wildlife habitat and protects one of the largest populations of birds of paradise in the world in a region where much of the landscape is cultivated for coffee and tea.

Protected landscape/seascape (Category V)

Category V protected areas are designed to protect the historical interaction of people and nature. Management objectives focus on safeguarding the tradition of this interaction, which may involve protecting traditional land uses or building practices, and social and cultural values. The Mount Emei and Leshan Giant Buddha in Sichuan, China, for example, contains both natural and cultural features of significance. The area is one of the four holy lands of Chinese Buddhism. Cultural artifacts present at the site include the 71 m-high statue of Buddha, which was carved into a prominent mountain peak in the early eighth century. Some 2000 people continue to live inside the area, including monks and nuns that reside in the temples and monasteries. Protection of the site is important for a number of endemic and globally threatened species of flora and fauna.

Managed resource protected area (Category VI)

Category VI protected areas are managed to ensure long-term protection of biological diversity and allow for sustainable resource use by communities. The Ngorogoro Crater Conservation Area of northern Tanzania is an area of global significance for its geological, cultural, and nat-

ural history. The pastoral Maasai people use the area for cattle grazing: it is estimated that some 285,000 cattle graze approximately 75% of the conservation area. While the conservation area was initially developed to benefit the Maasai, it is now recognized for its conservation value. The area is one of the largest, inactive, unbroken, and unflooded calderas in the world and is home to one of Africa's largest wildlife aggregations and an isolated relict population of the black rhinoceros (*Diceros bicornis*).

Biosphere Reserves, Ramsar Wetlands, and World Heritage Sites

Protected areas of all category levels can also be classified as Biosphere Reserves, Ramsar Wetlands, and World Heritage Sites. For example, the Ngorogoro Crater Conservation Area (a Category VI protected area) and Yellowstone National Park (a Category II protected area) are both Biosphere Reserves and World Heritage Sites.

There are currently 411 biosphere reserves in 94 countries dedicated under the UNESCO Man and the Biosphere Programme (Groombridge and Jenkins 2002). Biosphere Reserves are dedicated for a variety of objectives including research, monitoring, training, and demonstration as well as conservation. Importantly, biosphere reserves in the ideal are designed to create one or two areas of low-intensity human uses surrounding a strictly protected area at the core (Figure 14.3). In reality,

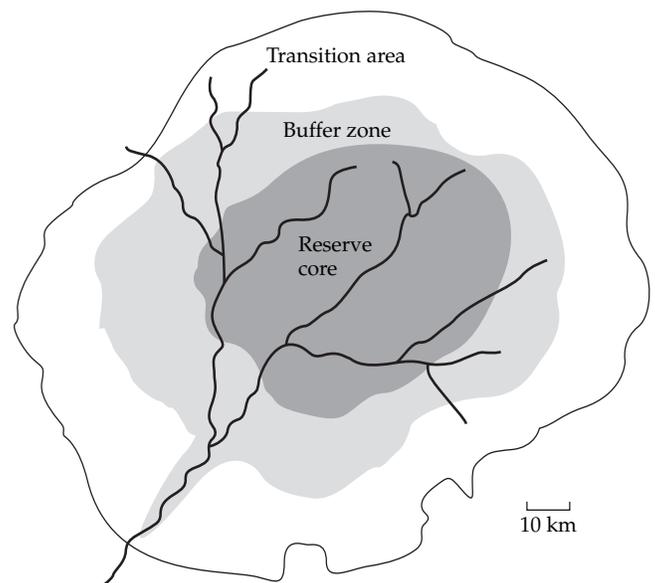


Figure 14.3 A schematic diagram of a biosphere reserve system, showing a core area that is accorded complete protection surrounded by a buffer zone where human uses are highly compatible with biodiversity conservation, which is in turn surrounded by a transition zone in which more intensive human uses are allowed. Beyond the biosphere reserve the full spectrum of human uses exist.

biosphere reserves often have a greater mix of uses, and are not as ideally shaped for biodiversity conservation (e.g., circular with a strict protected area at the core away from most human influences).

The Convention on Wetlands of International Importance was signed in 1971 in Ramsar (Iran) and provides a framework for international cooperation for the conservation of wetland habitats. The convention's mission is "the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world." This is the only global environmental convention whose mission is to target particular ecosystem types. Wetlands are broadly defined by the convention to include rivers, lakes, swamps, wet grasslands, coral reefs, estuaries, deltas, tidal flats, and near-shore marine areas, as well as some human-made wetlands such as fishponds, and rice paddies. Contracting parties and member countries of the convention commit to designating eligible areas as Ramsar wetlands, promoting wise use of wetlands, and consulting with other parties about management and implementation of convention regulations. In return, management tools and technical expertise are made available through the formation of partnerships and financing. As of March 2002, 1148 Ramsar wetlands had been designated, which cover approximately 96 million ha (Groombridge and Jenkins 2002).

The Convention Concerning the Protection of the World Cultural and Natural Heritage was adopted in Paris in 1972, and provides for the designation of areas of "outstanding universal value to all the peoples of the world" as World Heritage sites. The objectives of the Convention are to encourage member parties to track and report on the state of conservation of World Heritage sites; to provide technical assistance and professional training for site preservation, and when necessary, to provide emergency assistance for World Heritage sites in immediate danger. Other objectives are to enhance public awareness, encourage participation of local populations in the preservation of their cultural and natural heritage, and garner international cooperation in conservation of cultural and natural heritage. Signatory parties that uphold the standards may benefit from international recognition and assistance. Of the 788 World Heritage sites distributed among 124 countries, 611 are recognized for cultural values, 154 for natural values, and 23 for both cultural and natural values.

Strict protection versus multiple use

The role of strictly protected (Category I–IV) versus multiple use areas (Category V–VI) in meeting biodiversity conservation goals has been hotly debated. On the one hand, strictly protected areas that exclude hunting and

other extractive uses are likely to be most efficient at meeting biodiversity conservation goals. National parks and monuments, wildlife sanctuaries, and game reserves have formed the cornerstone of efforts to conserve biodiversity worldwide. However, exclusionary tactics may alienate people who benefit from extractive use of these resources, thus making multiple-use designations more amenable to achieving broad conservation goals. While each of the different types of protected area can contribute to conserving biodiversity, they vary in their contribution to biodiversity conservation relative to support of human populations (Redford and Sanderson 2000; Terborgh 2000; Adams 2004).

For example, territories established to protect the rights of traditional peoples may play a major role in conserving biodiversity in the region by prohibiting outsiders from pursuing extractive industries. However, local extinction of several species has been documented in indigenous reserves. Thus, we should recognize that indigenous people are not necessarily more likely than people from affluent, modern societies to be conservationists (Redford and Sanderson 2000). While each of the different types of protected area can contribute to a goal, consensus is emerging that specific reserves should be established for specific objectives. In the case of indigenous reserves, it may be advisable to establish a reserve that protects the rights of local peoples to their lands, but may or may not have specific biodiversity outcomes as a goal. If conservation goals are unlikely to be met in a given protected area, then alternative areas where they can be met should be identified.

There is growing recognition that conservation objectives are unlikely to be achieved by the dedication of strictly protected areas alone (Reid 1996). Thus, 23.3% of the total extent of the world's protected areas are assigned to Category VI (managed resource protected areas); protected areas managed mainly for the sustainable use of natural ecosystems (IUCN 1994; Chape et al. 2003; Figure 14.4). This category recognizes the role that protected areas play in sustaining the livelihoods of local people and therefore accommodate a degree of sustainable use as part of their management (Chape et al. 2003). Two of the world's largest protected areas are classified as Category VI: the Ar-Rub'al-Khali Wildlife Management Area in Saudi Arabia (640,000 km²) and the Great Barrier Reef Marine Park in Australia (345,400 km²). By comparison, less than 11% of the extent of the world's protected areas is assigned to Category Ia (strict nature reserve) and Category Ib (wilderness area) and 23.5% is assigned to Category II (national park) (IUCN 1994; Chape et al. 2003). Although there are many Category III (natural monument) protected areas, they generally cover only small geographic areas. A third of the world's protected areas have not been assigned an IUCN management category (see Figure 14.4).

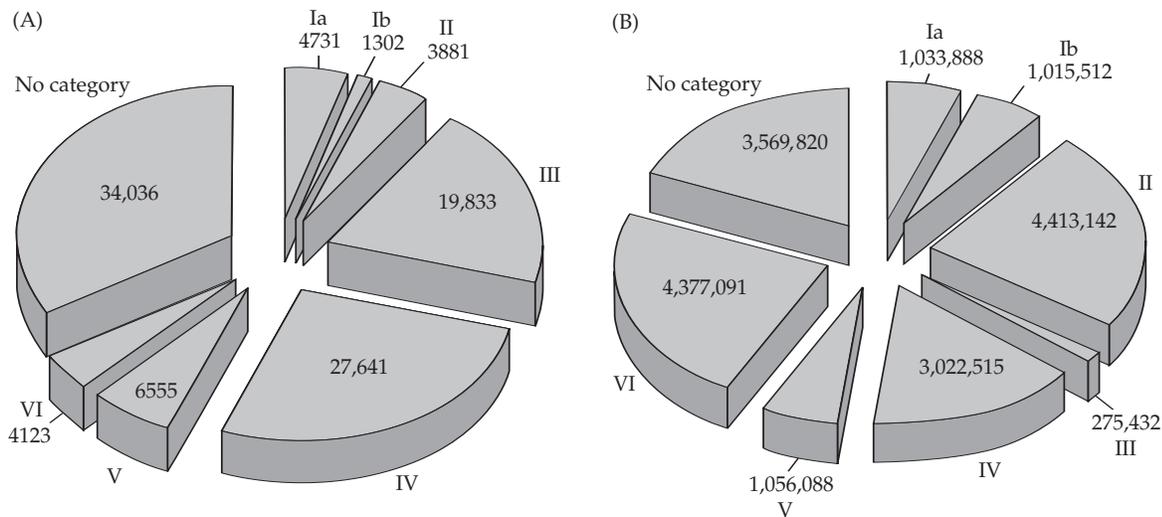


Figure 14.4 Number of protected areas (A) and area covered by protected areas (B) in km² by IUCN categories I–VI, and those unassigned to any IUCN category. (Modified from Chape et al. 2003.)

Management Effectiveness of Protected Areas

Threats to protected areas must be eliminated if the protected areas are to meet their objectives and contribute to biodiversity conservation (Essay 14.1 provides an example from the U.S. southwest). The IUCN established a framework for measuring management effectiveness, which considers: (1) issues related to design; (2) appropriateness of management; and (3) whether the objectives of protected areas are delivered. Design issues include considerations of size and shape, buffer zones, and linkage to other areas. Inappropriate design may result in protected areas that are too small to meet their conservation objectives. Without adequate or appropriate management, threats may continue in spite of legal designation of protected status (Case Study 14.1 discusses such challenges). Assessment of the level to which protected areas are meeting their stated objectives involves evaluation of both biological and social outcomes. These three criteria are being assessed for protected areas around the globe so that management can be improved and resources for protected area establishment can be mobilized.

For example, due to concern about deterioration of natural areas in Brazil, the World Wildlife Fund (WWF) and the Brazilian Environment Institute (IBAMA) evaluated 86 protected areas. Indicators were selected to measure both implementation of protected area goals, as well as vulnerability of each protected area. The study concluded that 47 of the protected areas were largely unimplemented, 32 were minimally implemented, and only seven were implemented to a reasonable degree. These results were used to lobby the Brazilian govern-

ment for increased funding and support for its reserve system. The approval of an investment scheme, whereby funds generated from protected areas are reinvested in the protected areas, resulted from this lobbying (Hockings et al. 2000).

Many protected areas lack resources, are inadequately managed, and thus do not achieve the conservation goals for which they were established. In addition, many face significant threats and challenges from inappropriate development both within and outside their boundaries (Reilly 1985; Liu et al. 2001). While legislative protection may be adequate to stop the exploitation of wildlife and habitat in some countries, in others, protected areas are vulnerable to hunting, encroachment, and timber harvesting. In some regions, protected areas are not even secure from vegetation clearing (Peres and Terborgh 1995; Menon et al. 2001).

In spite of these inadequacies, protected areas have been shown to effectively reach many of their goals (Chomitz 1996; Bruner et al. 2001). Even in cases of little or no management or infrastructure, species abundance and diversity is usually higher within protected areas than in the surrounding landscape, and many extinctions have been prevented by setting them aside. In regions of intense human impacts, protected areas are often the only remaining patches of native vegetation. In the marine realm, "there is compelling, irrefutable evidence that protecting areas from fishing leads to rapid increases in abundance, average body size, and biomass of exploited species. It also leads to increased diversity of species and recovery of habitat from fishing disturbance" (Roberts 2000).

In one study of management effectiveness, researchers used a questionnaire to collect data on land-use pressure, local conditions, and management activities of 93 pro-

ESSAY 14.1

Constant Vigilance

Maintaining a Fish Preserve in the Arid Southwestern United States

Jack E. Williams, *USDA Forest Service*

■ The desert oasis Ash Meadows has been the scene of many battles over land and water use. Endangered fishes—mostly species of pupfish—have been the focus of concern. One pivotal battle between the diminutive Devils Hole pupfish (*Cyprinodon diabolis*) and agricultural interests intent on withdrawing water from underground aquifers that feed springs in Ash Meadows was ultimately decided in the U.S. Supreme Court. On June 7, 1976, the Court upheld a lower court ruling for a permanent injunction of groundwater pumping until a safe water level for the pupfish could be established. During the court proceedings, the fate of the pupfish became the rallying cry for both conservationist and development interests (Figure A). Now, more than two decades later, and despite numerous endangered species listings and the creation of a National Wildlife Refuge at Ash Meadows, questions still remain concerning the survival of the Devils Hole pupfish and the area's many other endemic species.

Ash Meadows, located along the Nevada–California border approxi-

mately 145 km northwest of Las Vegas, consists of dozens of crystal-blue springs, wetlands, and alkaline uplands surrounded by the Mojave Desert. With 26 endemic taxa of fishes, springsnails, aquatic insects, and plants within the 95-km² oasis, it is the smallest area with such a rich and specialized biota in the U.S. (Deacon and Williams 1991).

As in most preserves, protection of Ash Meadows has come in fits and starts. On January 17, 1952, President Harry S. Truman declared 16 ha around Devil's Hole a disjunct portion of Death Valley National Monument. The natural values of Devil's Hole received further protection through court rulings during the 1970s. The major breakthrough for protection of the entire Ash Meadows area, however, came in June of 1984, when 5154 ha was acquired with the help of The Nature Conservancy and designated by Congress as the Ash Meadows National Wildlife Refuge. This halted plans for a large commercial and residential development, but not before some spring systems were drained and ditched and their flows diverted to create reservoirs. Certain areas within the refuge boundary remain privately owned, while the rest are managed by the Bureau of Land Management.

Introduction of nonnative species has been a long-term problem at Ash Meadows. During the 1960s, an illegal tropical fish farm provided the source for a wide variety of exotic species that flourished in the warm spring waters. Large populations of introduced mosquitofish (*Gambusia affinis*) and sailfin mollies (*Poecilia latipinna*) persist in many areas. Largemouth bass (*Micropterus salmoides*) and channel catfish (*Ictalurus punctatus*) have been introduced into reservoirs and have invaded springpools, where they prey on the native pupfish and speckled dace. Introduced bullfrogs and crayfish also prey on native species.

Recent management efforts have focused on control of exotics and restoration of natural spring channels and wetland habitats (Stein et al. 1999, 2000). Largemouth bass and channel catfish have been removed from spring systems

but still occur in reservoirs on the refuge and the risk of reinvasion is substantial. Smaller fishes such as mosquitofish and mollies are notoriously hard to control in areas like Ash Meadows, with its many shallow wetlands and interconnected waterways. Chemical treatment has been tried, but the effects of such control efforts on nontarget species, such as the tiny native springsnails, can be severe. Meanwhile, work continues to restore habitats. Channelized spring outflows have been restored and other spring flows have been diverted back into natural meandering channels.

Long-term maintenance of groundwater aquifers that feed Ash Meadows' spring systems is likely to be an even bigger challenge than control of nonnative species. Removal of groundwater from areas outside Ash Meadows may have negative consequences in the future by reducing springflows within Ash Meadows. With deep groundwater throughout much of the region flowing from northeast to southwest, water rights acquisition by the City of Las Vegas across much of southern Nevada is cause for concern.

These issues cannot be resolved easily by the National Wildlife Refuge system, which traditionally has focused on waterfowl production and hunting and is poorly equipped to deal with problems originating outside refuge boundaries. Even fishing activities on the refuge's reservoirs conflict with protection of the endemic spring-dwelling species because of the likelihood for exotic predatory fishes to invade spring systems. Restoration of natural springs, their outflows, and desert wetlands may conflict with desires for improved vehicle access, recreation facilities, and our tendency to intensively manage landscapes. And, as with the groundwater concerns, we are finding that ecosystem boundaries seldom conform to the administrative boundaries of the preserve.

To date, many urban and agricultural centers of the arid western U.S. have flourished with little regard for water consumption rates or effects on native biota. There are better alternatives for meeting the growing urban



Figure A Reserves protecting species such as the Devils Hole pupfish typically provoke visible responses on both sides of the development/conservation debate. (Photograph by E. P. Pister.)

needs for water than tapping our already-depleted surface and groundwaters. Professor James Deacon of the University of Nevada, Las Vegas, correctly questioned why society should spend billions of dollars on new water projects when it would be cheaper and environmentally more sound to “get

serious about retrofitting Las Vegas for water efficiency [and] then get serious about converting agriculture in the Colorado River basin to water efficiency and use the savings for urban needs—in both Nevada and California.”

Water use, whether surface waters on the refuge or groundwater from out-

side refuge boundaries, will continue to garner political attention. How society responds to these issues may be the ultimate court case for the Devils Hole pupfish and the other endemic life forms in Ash Meadows. ■

tected areas in 22 countries (Bruner et al. 2001). Only 17% of the protected areas, which had a median age of 23 years, had experienced net clearing since establishment (Figure 14.5). The protected areas were more heavily impacted by hunting and logging than by clearing, but these impacts were considerably reduced inside their boundaries as compared to their surroundings. Management effectiveness was correlated with basic management activities such as enforcement, degree of boundary demarcation, direct compensation to local communities, and deterrents to illegal activities (e.g., probability that a violator was sanctioned). The density of guards was especially important: the median density of guards in the 15 most effective protected areas was more than eight times higher than in the 15 least-effective protected areas.

A recent report by World Wildlife Fund (WWF) showed that management effectiveness is correlated with IUCN category, and that World Heritage, UNESCO Man and Biosphere Reserve, and Ramsar sites are as effective as other types of protected areas at meeting conservation objectives. An analysis of threats showed that poaching, logging, encroachment, and collection of nontimber forest products, were more of a problem than all other threats combined (WWF International 2004).

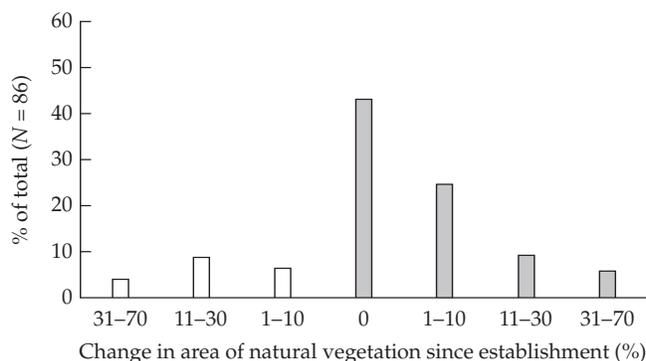


Figure 14.5 Change in the area of natural vegetation since establishment for 86 tropical protected areas. White bars denote loss of areas and gray bars denote an increase in area (due to regrowth and restoration). The majority of protected areas have either experienced no net clearing or have actually increased natural vegetative cover. Protected areas have a median age of 23 years. (Modified from Bruner et al. 2001.)

The Need for Reserve Systems

Single protected areas will rarely be of adequate size or scope to conserve a representative sample of the biodiversity of a region, therefore entire reserve systems are critical for the conservation of biodiversity. However, a reserve system need not be comprised entirely of areas with strict protection. For example, it might be comprised of a combination of strictly protected areas that are off-limits, areas that afford protection while also allowing light use, and indigenous lands where traditional harvesting practices can continue.

This is not to say that single protected areas are unimportant, even if they do not harbor great species richness. Certain areas may, for example, be low in richness but hold significant populations of unique or critically threatened species, or be the only site in the world where a species is found. The Kihansi Spray Toad *Nectophrynoides asperginnis*, for example, occurs only in the spray of a single waterfall on the escarpment of the Udzungwa Mountains, Tanzania (Poynton et al. 1998). The fate of the world’s population of this toad thus depends on the protection of this single waterfall. In most cases, however, single protected areas are rarely, if ever, sufficient to represent an entire region, and thus we need to develop networks of reserve systems that can achieve our larger goals for biodiversity conservation.

The distribution of protected areas relative to habitat type is uneven, which is partly a legacy of ad hoc or politically expedient decisions about protected area establishment (Pressey 1994). Early efforts toward protected area establishment tended to focus on designation of single protected areas rather than entire reserve systems. Analyses of reserve systems at global, regional, or national scales indicate that there are gaps and biases in the representation of biodiversity (e.g., Scott et al. 2001; Andelman and Willig 2003; Rodrigues et al. 2004a). **Gap analysis** (Scott et al. 1987; Jennings 2000) is an approach used to identify “gaps,” or areas of under-representation in the existing reserve system, by comparing the distribution of protected areas with the distribution of species, vegetation types, or other types of biodiversity (Essay 14.2).

In 1992, the Fourth Congress on National Parks and Protected Areas (Caracas, Venezuela) called for protection of at least 10% of each major biome by the Year 2000

ESSAY 14.2

Gap Analysis A Spatial Tool for Conservation Planning

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■ Gap analysis is an analytical approach to conservation assessment that provides information that can be used to “keep common species common” by identifying those animal and plant species or communities that are not adequately represented in existing conservation lands. Gap analysis can be conducted at a variety of spatial scales and for whatever suite of animal and plant communities is of biological or political interest. Information from gap analyses can be used by land managers, planners, scientists, and policymakers to provide information they need to make more informed decisions when identifying priority areas for conservation.

Gap analysis had its beginnings in Hawaii (Kepler and Scott 1985; Scott et al. 1986; Scott et al. 1993) when information on the distribution of endangered Hawaiian forest birds was compared, using a geographical information system (GIS), with the occurrence of areas dedicated to the long-term conservation of native plants and animals. Results of this comparison showed almost complete lack of overlap between area of occupancy of endangered birds and areas established to protect native species (Figure A). This information was used by agency personnel and policymakers to establish Hakalau Forest National Wildlife Refuge. The first state-wide gap analysis to assess conservation status of vertebrate species and dominant habitats was in Idaho (Caicco et al. 1995; Kiester et al. 1996). Since then, gap analyses have been completed or are underway in every state of the U.S. and in many other countries.

Gap assessments are conducted using maps of species predicted distributions (Scott et al. 2002) and mapped land cover types (Table A). Land cover maps are developed using satellite imagery (e.g., Landsat 7) as the base data in a GIS. Then, using field plots, serial photos, and other sources are used to help classify the unique spectral classes derived from the imagery into distinct vegetation classes.

Predicted species distributions are based on existing range maps,

known occurrences, and other distributional information combined with information on the habitat affinities for the species (Scott et al. 1993; Karl et al. 1999). Distribution maps for individual species can be overlaid using a GIS to create maps of species richness (Scott et al. 1987) for any group of species that is of political or biological interest. Additional maps of land ownership and land management are also created. These maps are then overlaid with the

maps of species distribution and mapped cover types to assess what area, and percentages of mapped occurrences of the species and cover types occurring in that area, fall within the existing conservation estate.

Gap analyses have been conducted at a diversity of spatial and thematic scales, from state-and ecoregional- to global-level assessments, and including terrestrial, freshwater, and marine components. Dozens of U.S. states have

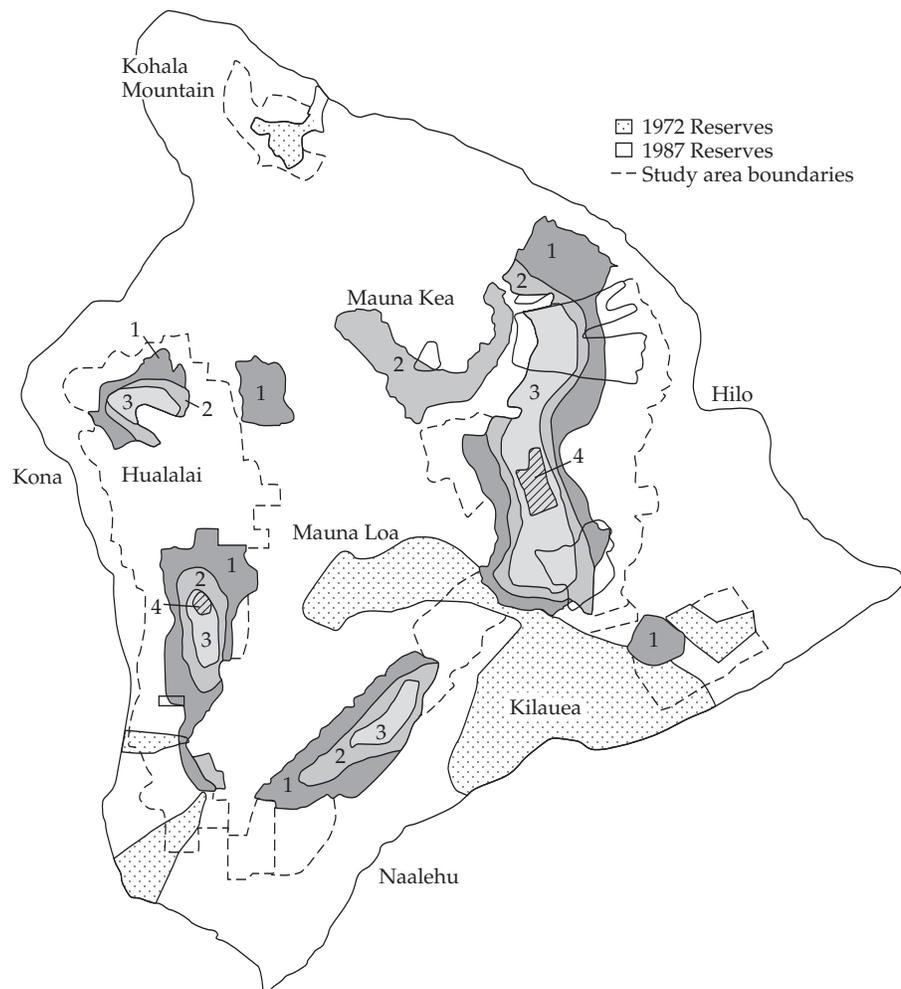


Figure A Basics of Gap analysis; distribution of endangered Hawaiian finches in relation to existing nature reserves on the island of Hawaii in 1982. Note that reserves established by 1972 had almost no overlap with any finch species. New reserves established in 1987 have improved this situation based on the results of gap analysis. (Modified from Kepler and Scott 1985.)

TABLE A Six Fundamentals of Gap Analysis

1. Maps existing vegetation
2. Maps predicted distribution of native species
3. Maps landownership for public lands and land management status for all lands
4. Shows the current distribution of protected areas
5. Compares distribution of any species, group of species or vegetation types of interest with the conservation network
6. Provides an objective data set for local regional state and national interests to make decisions regarding conservation of species and ecosystems

completed gap analysis, and many more are in progress (Figure B shows a flowchart of state-level gap processes). Wright et al. (2001) and Davis et al. (1995) have conducted multi-state conservation assessments using gap analysis, while Stoms et al. (1998) have conducted gap analyses within a single ecoregion. At the national scale, Scott et al. (2001) conducted a conservation assessment of the occurrence of dominant cover types within existing nature reserves and of the distribution of existing nature reserves by elevation and soil types. Crumpacker et al. (1998) assessed the occurrence of potential vegetation types on all public lands in the U.S. Additionally, there has recently been a conservation assessment of eco-

logical content and context of refuges in the U.S. Fish and Wildlife Services National Wildlife Refuge System in the coterminous U.S. (Scott and Loveland in press). Internationally, gap analyses have been conducted in both the terrestrial and marine realm, across parts of Africa, Asia, Europe, and the Middle East.

Gap provides decision-makers with information that can be used to make more-informed decisions regarding land use. The biggest single misapplication of gap is to take information from a gap analysis conducted at one scale and test its predictions or apply it at another scale. For example, a manager could be badly misled if he used predicted occurrence of species and vege-

tation types from a gap analysis conducted with a minimum mapping unit of 40 ha to make decisions within a 200 ha reserve. Gap is not a substitute for endangered and threatened species management planning or research, neither is it a thorough nationwide inventory of biological resources, many of which cannot be mapped at a continental or nationwide scale. Also related to scale, gap maps for species distribution should be done at a scale appropriate to the species or a segment of the population of the species.

Gap analysis was born of the realization that a species-by-species approach to conservation is not effective for regional planning (Scott and Csuti 1997). Single species planning has proven reactive, delayed until a species was teetering on the brink of extinction and thus requiring large sums of money and personnel to mount a species recovery effort. Gap analysis is a *proactive* effort to keep species off the endangered species list and special management lists by protecting them and their associated habitat types while they are still common. This approach avoids many of the conflicts inherent in recovering endangered species.

For further information on gap analysis we refer readers to the USGS Gap Analysis Program website (see <http://www.gap.uidaho.edu/>) which provides an extensive data base of literature and information on state, regional, national, and international gap analysis efforts. ■

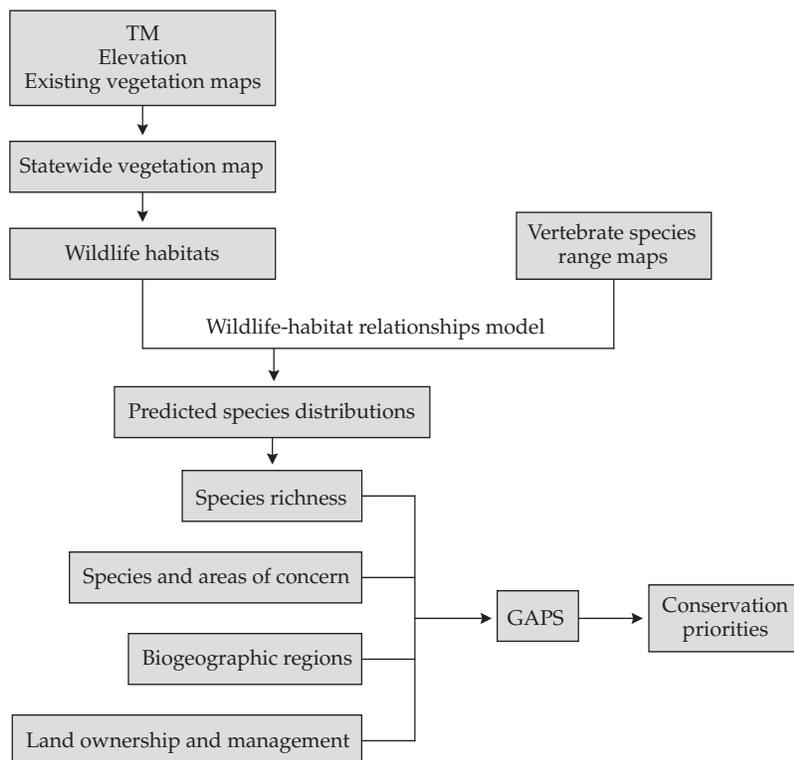
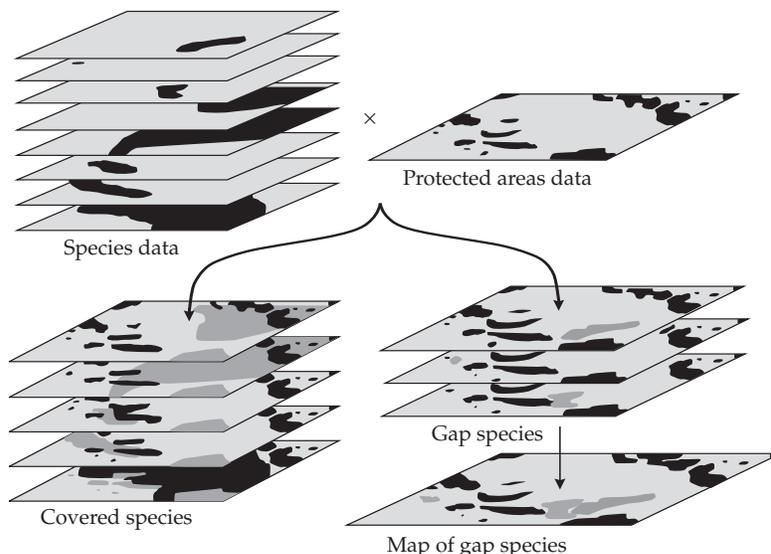


Figure B Flow chart of Gap analysis as pertinent to state-level analysis, but which can be adapted to other scales. Analyses of overlapping data layers allow identification of gaps between predicted and actual species occurrences and protected areas, and thus provide material for deciding conservation priorities. (Courtesy of California Gap Analysis.)

Figure 14.6 Illustration of the methods used in the Global Gap Analysis. Data on species distributions were overlaid with the distribution of protected areas using GIS. Species whose distribution coincided at least partially with a protected area were considered “covered” and those whose distributions did not were considered “gap species.” An overlay of the distributions of gap species produces a map that highlights regions where new protected areas are needed to protect these vertebrate gap species. (Modified from Rodrigues et al. 2004a.)



(IUCN 1993), and this has become a major national and international guideline. In 2003, the Fifth World Parks Congress (Durban, South Africa) announced that 11.5% of Earth’s land surface is now under some form of protection, and that the 10% target has been reached for nine out of 14 major biomes (IUCN 2003).

Ironically, often it is the species of most conservation concern (i.e., threatened and small range species) that are most poorly represented within protected areas. Recently, the extent to which our existing protected areas include vertebrate species was assessed in the Global Gap Analysis Project (Rodrigues et al. 2004a,b; Brooks et al. 2004). The Global Gap Analysis combined data from the World Database on Protected Areas with distributional data for 11,633 species of mammals, amphibians, freshwater turtles and tortoises, and globally threatened birds. Species distribution maps were overlaid onto protected area maps using geographic information systems (GIS) to assess how well each species was represented in protected areas, and to identify *gap species*; those that are not covered in any part of their range (Figure 14.6). The analysis revealed 1424 species that are not protected in any part of their range, 804 of which threatened with extinction (20% of all threatened species analyzed). These numbers nearly double when considering the species that are represented only by very marginal overlaps with existing protected areas. Amphibians, overall, are the least well represented in protected areas, mainly due to their smaller ranges and higher levels of endemism, but also because they have received relatively less conservation attention.

The Global Gap Analysis also highlighted the skew in the distribution of protected areas, both geographically and in terms of size. For example, in the New World, the median size of strictly protected areas (Category I and II) is only 4.86 km² and 57% are less than 10 km² (Andelman and Willig 2003). In addition, the distribution of

protected areas in the New World is skewed towards higher latitudes: 35% of the total area of strictly protected areas is found in Alaska (Andelman and Willig 2003). Globally, only 46% of protected areas are found in the tropics, where 76% of all species reside (Rodrigues et al. 2004a). Tropical forests, especially areas of topographic complexity, and islands were highlighted in the Global Gap Analysis as urgent priorities for the expansion of the global network of protected areas (see Plate 6). These areas are in regions long recognized to be centers of endemism that are suffering high levels of habitat destruction (Myers et al. 2000). Thus, the analysis identified regions of both high irreplaceability and high threat as priorities for the expansion of the protected area network (Figure 14.7). Further, they recommend that detailed analyses be initiated to design new reserve systems in these priority areas.

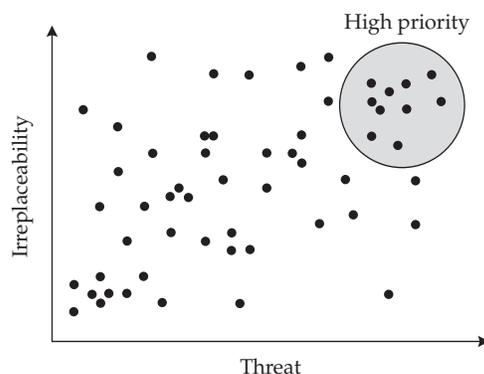


Figure 14.7 The Global Gap Analysis evaluated protected and unprotected sites for their irreplaceability and level of threat. Unprotected areas that ranked highly in both axes were highlighted as highest priority regions for the expansion of reserve systems. (Modified from Rodrigues et al. 2004a.)

Creating a global, ecologically representative reserve system will require investments of U.S.\$3–\$11 billion per year over the next 30 years (according to estimates by James et al. 2001; Pimm et al. 2001). At the same time, globally intact ecosystems are being converted to human-dominated uses at a rate of over 1% per year (Balmford et al. 2002), creating an even more urgent need for the designation of new protected areas. Thus, there is a need to prioritize the allocation of scarce conservation resources to the expansion of existing protected areas and the creation of new ones so that the returns for biodiversity conservation are maximized.

Although protected areas comprise 12.65% of Earth's surface as of 2005, marine protected areas still make up a very small component: 0.5% of the surface area of the oceans are protected, which is equal to 1.89 million km² or 9.1% of the area of all protected areas (see Plate 5). The largest marine protected area is the Great Barrier Reef Marine Park in Australia (345,400 km²), for which one-third is fully protected from extractive uses, such as fishing. Thus, there is a large need to expand our network of marine protected areas. One such effort is described by Satie Airame and Deborah Brosnan in Case Study 14.2.

Approaches to Planning Reserve Systems

The ecological purpose of a reserve system is to include and sustain representative samples of the full range of biodiversity and ecosystem processes of the region in which it lies (Margules and Pressey 2000). Some of the first reserves created primarily for biodiversity protection aimed to conserve a **flagship species**, usually a large mammal that is compelling to the public (Figure 14.8). While protected areas should represent and maintain biodiversity and separate it from the processes that threaten its persistence (Margules and Pressey 2000), historically, biodiversity considerations have played a small role in the selection of protected areas. Other factors, such as suitability for alternative land uses, availability, scenic beauty, and recreational value have played a more important role.

The trend of protecting land left over from major exploitative uses is recognized throughout the world, with examples from Australia (Pressey 1994; Pressey and Tully 1994), New Zealand (Mark 1985), Canada, the United Kingdom (Henderson 1992), the United States (Runte 1972; Shands and Healy 1977; Scott et al. 2001), Africa, and Japan (Pressey 1994). Strong evidence for the perception of protected areas as “worthless lands” in Australia comes from the revocations of protected areas after it was realized that they were preventing the exploitation of some resource of commercial value. For example, between 1939 and 1984 there were 23 revocations

of protected areas in Tasmania (Australia), the majority of which were national parks (Mercer and Peterson 1986). Some of the larger scale national park revocations were due to pressure from forestry, hydroelectric developments, and mining interests. In the 1950s there were revocations of protected areas in South Australia due to the expansion of the rural sector and even more recently to allow for mineral exploration.

Selecting protected areas in an ad hoc or opportunistic manner generally results in the conservation of economically marginal land and reserve systems that do not represent the full range of biodiversity (Pressey and Tully 1994). Representational biases in reserve systems often occur because certain environments are more politically and economically expedient to protect, leaving other areas poorly protected, regardless of their conservation value. Consequently, many reserve systems are dominated by dry, infertile, waterlogged, saline, or steep habitats.

When biodiversity conservation is the primary goal, reserve systems are often created for one of three purposes:

1. Protect particular species (e.g., threatened, flagship, or **umbrella species** [wide-ranging species whose requirements include those of many other species])
2. Preserve biodiversity, focusing on areas of high species richness (e.g., tropical rainforests or coral reefs, or areas with high endemism)
3. Preserve large and functioning ecosystems and their associated ecosystem services (e.g., catchments or watersheds)

Scoring systems based on these reserve system goals were developed in the 1980s in an attempt to provide an explicit and rational basis for reserve system design (Margules and Usher 1981; Smith and Theberge 1987; Pressey and Nicholls 1989). These systems scored or rated potential protected areas against several criteria to provide an overall indication of their conservation value. The main limitation of scoring approaches is that they: lack explicit goals, cannot deal with synergistic benefits of multiple areas, and cannot tell us when we have conserved enough. Therefore, when using scoring approaches, it is impossible to determine when full representation has been accomplished. For example, knowing that one set of species is globally imperiled, while another set of species is widespread but demonstrably secure, can be very effective in focusing our attention where it is most needed. However, this alone does not help us decide how many populations of the globally-imperiled species we should include in our reserve system. Scoring approaches generally lead to inefficient and unrepresentative reserve systems (Bedward et al. 1991; Margules et al. 1991; Pressey 1997).

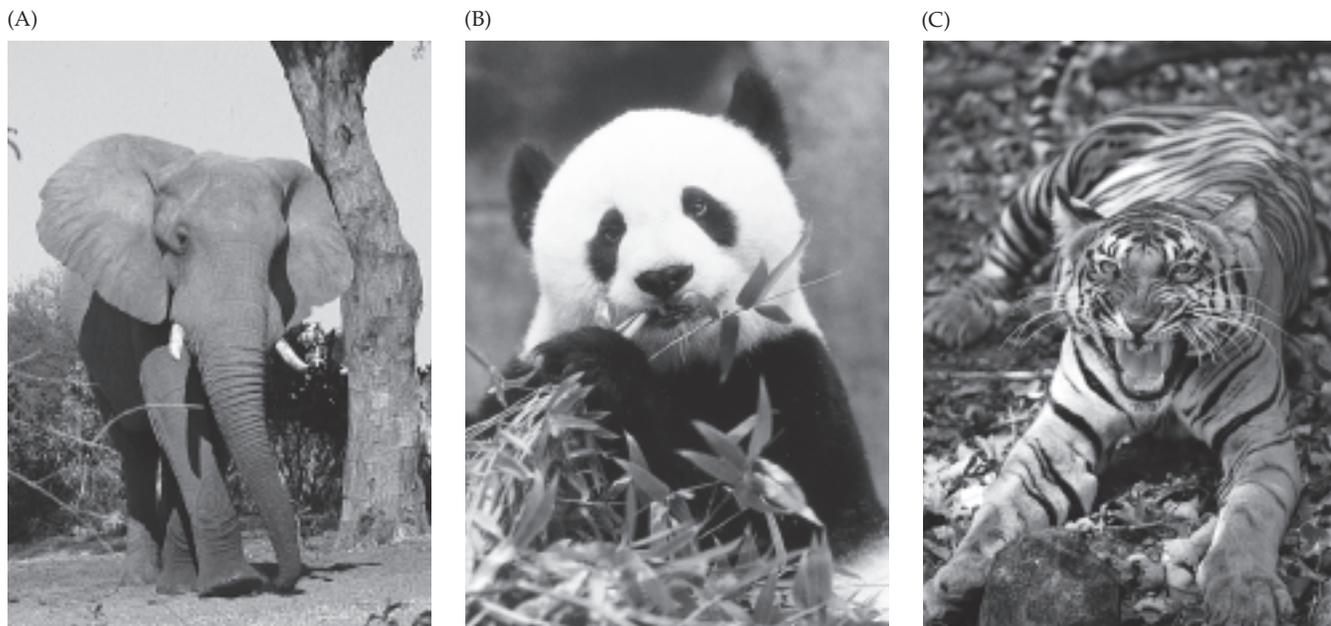


Figure 14.8 Protected areas are often established primarily to conserve a single species, usually large, high-profile vertebrates, such as (A) African elephant (*Loxodonta africana*), (B) giant panda (*Ailuropoda melanoleuca*), or (C) Bengal tiger (*Panthera tigris*). (A, photograph by G. J. James/Biological Photo Service; B, by Ron Garrison © San Diego Zoo; C, by Vivek Sinha/Biological Photo Service.)

The selection of protected areas using statistical analyses of multiple variables (multivariate environmental space; Belbin 1995; Faith and Walker 1996) or using gap analysis (Scott et al. 1993) also aims to identify a system of representative and complementary protected areas. Multivariate environmental space procedures select protected areas that allow the biggest incremental gain in capturing the range of environmental variation in a region. An underlying assumption of these approaches is that environmental space can serve as a surrogate for the range of biodiversity of a region.

Recent research efforts in the field of conservation planning have focused on the development of principles and tools to design efficient reserve systems that represent as much biodiversity as possible for a fixed cost. In the next sections, we review the principles behind systematic approaches for creating and designing reserve systems, referred to herein as **systematic conservation planning**. After the reserve system is created, the next set of challenges for conservation planning relate to the political and physical establishment of the reserve system.

Systematic conservation planning

Approaches to systematic conservation planning recognize that, due to constraints on the amount of land that can be set aside for biodiversity conservation, there is a need to conserve biodiversity in the most efficient manner possible (Pressey et al. 1993). Therefore, a common goal of

systematic conservation planning is to meet quantitative conservation objectives, such as conserving 15% of each habitat type within a system of complementary protected areas, as cheaply as possible. Conservation objectives (referred to by some authors as “targets”) are operational definitions of a decision to reach a certain level of conservation for particular biodiversity features (Pressey et al. 2003). These objectives provide a clear purpose for conservation planning and improve the accountability and defensibility of the process.

Systematic conservation planning involves finding the best set of potential protected areas that satisfies a number of principles: **comprehensiveness**, **representativeness**, **adequacy**, **efficiency**, flexibility, risk spreading, and **irreplaceability**. In addition, principles regarding protected areas connectivity and shape are usually included. We explain and consider these concepts next.

COMPREHENSIVENESS A comprehensive reserve system is one that contains examples of many biodiversity features, where biodiversity features might include species, habitats, or ecological processes. While ideally we would like to include a sample of every kind of biodiversity feature in our reserve system this is rarely achieved.

REPRESENTATIVENESS Realistically, a fully protected reserve system will cover only a fraction of the landscape. Consequently, we will not be able to protect all the vari-

ety within most features, but rather our reserve system will only sample each biodiversity feature. Ideally, we would like each sample to be representative of that feature. For example, if we wish to conserve populations of a particular species, or samples of a habitat, we would prefer that the samples we choose cover the range of variation in that species and/or habitat. Despite its importance, the notion of representativeness is rarely explicitly dealt with in conservation planning. The concept of representativeness is closely related to the idea of comprehensiveness because if we define biodiversity features at a finer scale (e.g., subdivide a habitat type into several types), then comprehensively sampling the new, less coarsely defined habitat types, is equivalent to representing the coarser habitat type.

ADEQUACY Even if we manage to dedicate enough protected areas to comprehensively protect representative samples of all biodiversity features, we cannot be sure that these features will persist in the reserve system. Ideally we would like to have a reserve system that is adequate to ensure the persistence and continued evolution of all features contained within it. This aspect of conservation planning is not well developed. Practitioners generally deal with the idea of adequacy by setting conservation objectives in the form of a target percentage of original extent or a target population size for each species as determined by population viability analysis (see Essay 12.2) or expert opinion.

EFFICIENCY A simple way to abide by the principles of comprehensiveness, representativeness, and adequacy is to conserve everything. In practice this is impossible. The principle of efficiency is that we try to achieve our objectives for the least possible cost. Cost is often taken to be the area of land or sea protected, but may include purchase and management costs, or the costs of lost economic development. Efficiency is important, because it minimizes the possibility of constructing a reserve system that is too large and expensive to manage. An efficient reserve system is more likely to succeed in the face of competing interests. It is also a sound platform from which to expand a reserve system.

FLEXIBILITY A flexible conservation plan is one that enables us to achieve our objectives efficiently in a number of ways. Flexibility might be important to take advantage of opportunities that arise for conservation, such as a block of land with high conservation value becoming available for purchase.

RISK SPREADING There is a natural tension between the principle of connectivity and the idea of risk spreading. Catastrophes such as hurricanes and disease, and illegal habitat destruction can affect the conservation values of

any area, even if it is protected. Close, well connected protected areas might be a disadvantage if the arrangement increases the chance of disease spread, nonnative species invasion, or allows for disturbance events to move from one protected area to another. There are values of spreading risk that may outweigh any advantages to be gained from the elevated dispersal rates and increased recolonization potential that might be provided when protected areas are in close proximity. Risk spreading can be achieved by separating protected areas by a minimum distance.

IRREPLACEABILITY The irreplaceability of an area reflects how important its inclusion is in the reserve system if we are to meet all our conservation objectives efficiently. A completely irreplaceable area is essential to meeting conservation objectives, whereas an area with a very low irreplaceability can be substituted by other sites. The measure of irreplaceability provides a quantitative assessment of the contribution of unselected areas for meeting conservation objectives (Pressey et al. 1993; Pressey et al. 1994; Ferrier et al. 2000). Irreplaceability can be viewed in two contexts; the likelihood that an area is necessary to achieve the conservation objectives for the features it contains, or the extent to which the options for achieving conservation objectives are reduced if the area is unavailable for conservation.

If an area of high irreplaceability is not conserved, one or more features could be lost. Some areas are completely unique and vital to conservation objectives, and these must be included in the reserve system if at all possible. Irreplaceability can help determine which areas are priorities for conservation, but other constraints and considerations may mean that areas with lower irreplaceability are more suitable for conservation. For example, the vulnerability, condition, and/or cost of an area might influence its priority for protection.

CONNECTIVITY Maintaining connections among protected areas is often an essential component of a reserve system. There are several reasons why connectivity might be important. First, species with populations distributed patchily across the landscape depend on dispersal for maintaining genetic variability; without movement between protected areas, populations may experience problems associated with inbreeding. Second, wide-ranging species, such as the African elephant (*Loxodonta africana*), may require more space than could reasonably occur in a single protected area, and their survival will depend on their ability to move between protected areas. Third, climate change is likely to alter the ranges of many species, and ensuring that the landscape mosaic between reserves of natural habitat remains hospitable will influence whether such species will persist into the future. Finally, conservation activities outside protected

areas considerably increase the opportunities for landscape planning, which can address the sources of threats to biodiversity and improve ecological functioning. Therefore, while the primary focus of a reserve system is to secure areas most critical for the protection of biodiversity, thinking beyond the borders and planning for the landscape mosaic is also imperative to meeting the objectives of reserve systems.

Connectivity for ecosystem processes, such as water flow or fire regimes, also should be explicitly incorporated into conservation planning (Possingham et al. 2005), however there are few examples of this being achieved. For example in conserving riparian systems we might be interested in reserve systems that not only conserve a representative sample of each kind of riparian habitat, but that also ensure that each protected area is a self-contained catchment (i.e., all flows of water are contained within a given protected area). Similarly with processes such as fire, we may wish to minimize the chance that a single protected area is completely affected by a single fire. In cases in which vegetation mosaics are important for biodiversity conservation, each protected area should be of sufficient size to contain a complete range of fire-induced successional states. Using such process-driven objectives as opposed to pattern-driven objectives in systematic conservation planning is still in its infancy (Pressey et al. 2003).

PROTECTED AREA SHAPE There are both ecological and economic reasons why protected areas should be large with low edge-to-area ratios and be well connected (as discussed previously). Long thin protected areas with high edge-to-area ratios are sensitive to edge effects caused by biotic interactions such as predation or abiotic factors such as humidity and wind (Fagan et al. 1999). For edge-sensitive species, the effectiveness of a protected area is reduced if it has a high edge-to-area ratio. Equally, from an economic perspective, boundaries should be minimized to reduce maintenance costs.

The concept of corridors between protected areas arose as a corollary of the theory of island biogeography (see Chapter 7). The definition of corridors includes the traditional “strip of land that differs from the adjacent landscape on both sides, linking two or more protected areas,” and “stepping stones” of suitable habitat for various species within a matrix of less-suitable habitat that can serve as a “path” between protected areas (Earn et al. 2000). A large-scale biodiversity conservation corridor may contain several isolated or semi-isolated protected areas, each of which constitutes a “nucleus” of habitat connected through corridors (Sanderson et al. 2002). The size, shape, and management of corridors varies, but their primary purpose is to promote connectivity and allow movement of individuals between otherwise isolated patches of habitat.

Corridors and stepping stones are particularly prone to problems arising from small size and high edge-to-area ratios. Thus, a significant challenge is to identify potential corridors that are relatively robust to these problems. However, achieving this can add significantly to the costs of a reserve system.

MINIMIZING FRAGMENTATION OF RESERVE SYSTEMS In fragmented and convoluted reserve systems, edges are long relative to area. The degree of fragmentation among protected areas in a reserve system can be measured by the boundary length of the reserve system divided by the area. The higher this ratio the more fragmented is the reserve system. One simple measure of how compact or clustered a reserve system is can be calculated from the ratio of the boundary length of the reserve system and the circumference of a circle of the same area (Possingham et al. 2000):

$$\frac{\text{Boundary Length}}{2\sqrt{\pi \times \text{Area}}}$$

A circle is the most compact shape possible, so this is the ratio of the boundary length to the theoretical minimum and is a dimensionless measure. Values approaching 1 resemble the shape of a circle and are relatively compact and unfragmented.

We can make a reserve system that is not fragmented or convoluted by setting an objective that takes into account the length of the reserve system boundary. By minimizing a combination of reserve system boundary length and cost, we can create efficient and compact reserve systems. As we place more emphasis on minimizing boundary length, costs may be compromised, and vice versa (Figure 14.9).

Each of these principles can help create a reserve system that will achieve broad conservation objectives of adequately representing biodiversity in viable populations. However, in practice, applying these principles often requires data we do not have, and may involve complex optimization algorithms and difficult tradeoffs.

The use of surrogates for reserve system planning

The principles of comprehensiveness, adequacy, and representativeness require that a reserve system must capture all the biodiversity of a region. However, information on biodiversity, even for well-known taxa such as birds and mammals, is incomplete. Therefore, the features used for conservation planning must act as **surrogates** for total biodiversity (Ferrier et al. 2000). Many types of surrogates have been proposed including well-known taxonomic groups, species assemblages, plant communities, and various spatial classifications of land and water, such as forest or marine benthic types (Margules and Pressey 2000; Ferrier 2002; Ferrier et al. 2002).

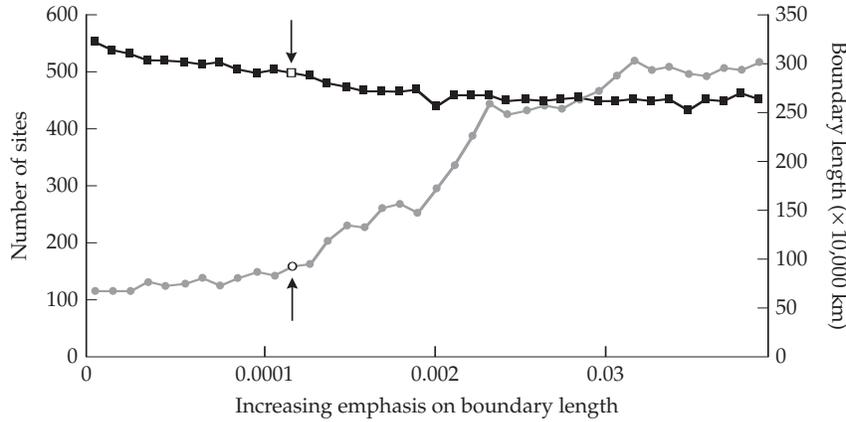


Figure 14.9 Maximizing the ecological effectiveness of a reserve system can involve analyses of the tradeoff between boundary length (which increases edge effects) and the number of areas protected. Pictured is the increase in boundary length (black line, measured in km × 10,000) and number of additional areas protected (gray line) for a hypothetical reserve system. The arrows indicate a reserve system that represents a reasonable compromise between increasing number of areas protected and boundary length: it reduces the boundary length by 6.7%, while it increases the number of areas protected by 22%.

The level of support in the literature for various surrogates has been variable (see Reyers and van Jaarsveld 2000; Beger et al. 2003; Ferrier 2002; Faith et al. 2004; Pressey 2004 for an introduction to the literature). Ideas about the properties that surrogates should have are emerging to efficiently represent other elements of biodiversity (Howard et al. 1998; Oliver et al. 1998; Su et al. 2004). However, a reserve system designed to be optimal and adequate for a single or even a set of species is not likely to satisfy the requirements of all species or biodiversity, even if species have similar spatial distributions (Andelman and Fagan 2000; Figure 14.10). Further, since it is unlikely that it will ever be possible to measure the

variation of biodiversity within or between regions, the true effectiveness of biodiversity surrogates is indeterminate (Flather et al. 1997).

One conclusion from all studies testing the effectiveness of surrogates is that there will never be a perfect surrogate or suite of surrogates. The choice of surrogate will depend on both the presumed effectiveness of the surrogates available, and the amount of time, cost and effort required to develop alternative ones (Pressey and Ferrier 1995; Ferrier 1997, 2002). Conservation planning practitioners therefore should make the best use of all available environmental and biological data to inform decision-making.

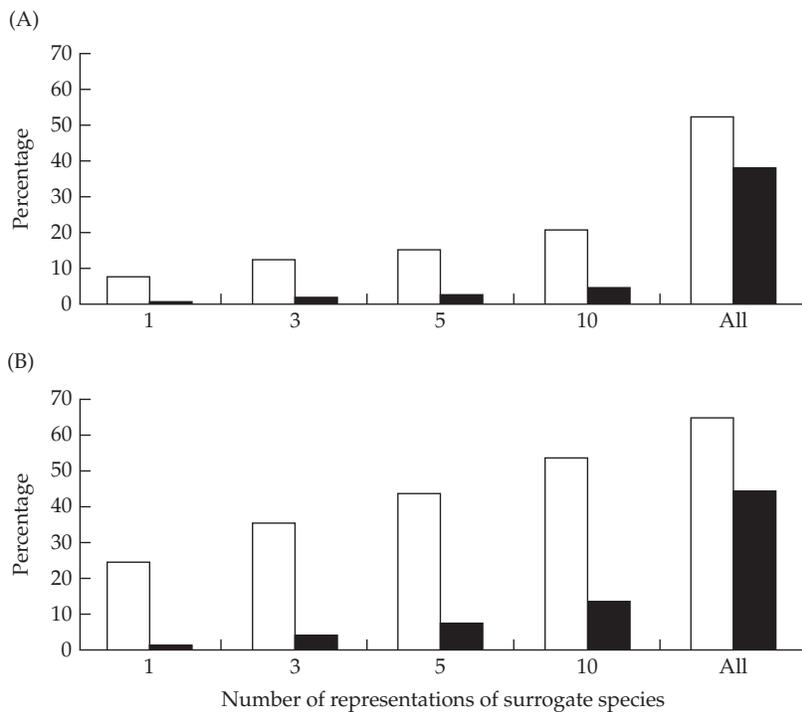


Figure 14.10 Percentage of all species (white bars) represented in a reserve system selected by conserving 1, 3, 5, 10 and all occurrences of charismatic (A) or habitat specialist (B) surrogate species using data from the Columbia Plateau region of Washington. As the number of occurrences increases, so does the number of sites needed in (and therefore the cost of) the reserve system (black bars). (Modified from Andelman and Fagan 2000.)

Tools for systematic conservation planning

Recently, an array of systematic conservation planning techniques have been developed that are goal-directed, transparent, defensible, flexible, amenable to being solved with mathematical algorithms, and aim to efficiently meet quantitative objectives within a system of representative and complementary protected areas (Margules and Pressey 2000; Pressey 2002). Systematic conservation planning is an evolving discipline at the interface of biological, mathematical, and social sciences. The process does not preclude expert judgment and it has been recognized that systematic and expert-driven approaches should be combined (Pressey and Cowling 2001; Cowling et al. 2003b). Systematic conservation planning has informed conservation in both terrestrial (e.g., Pressey 1998; Cowling and Pressey 2003) and marine realms (e.g., Ferdana 2002; Airame et al. 2003; Great Barrier Reef Marine Park Authority 2003).

Conservation planning has made extensive use of computer algorithms to aid decision making. The aim of systematic conservation planning is to select areas to be part of a reserve system by either minimizing or maximizing the value of an objective function, subject to constraints that control the choices made. These formulations are referred to as the minimum-set and the maximal coverage problems. These methods are described in Box 14.2.

The objective of the minimum-set problem is to minimize resources expended, subject to the constraint that all features meet their conservation objectives. The objective of the maximal coverage problem is to maximize protection of features subject to the constraint that the resources expended do not exceed a fixed cost. The minimum-set problem aims to achieve the conservation objectives allocated to each feature in the most efficient manner and specifies a baseline reserve system obtainable for minimal cost. From the perspective of biodiversity conservation, the largest reserve system possible will always be desirable; however, in reality the extent of any reserve system will be limited by social and economic constraints. Therefore, building a reserve system requires observing the principle of efficiency defined earlier.

For example, a systematic conservation plan has been developed for the Greater Yellowstone Ecosystem, an area with high wilderness qualities that serves as important habitat for native carnivores, including grizzly bears (*Ursus arctos*) (Noss et al. 2002). Presently, 36% of the ecosystem is privately owned and 64% is publicly owned. Existing protected areas cover 27% of the ecosystem, but these protected areas are not ecologically representative. The aim of the conservation plan is to protect special elements (including threatened species and communities), represent environmental variation (in vegetation, geoclimate, and aquatic habitat), and secure habitat

for focal species (in particular, the grizzly bear, gray wolf [*Canis lupus*], and wolverine [*Gulo gulo*]).

The data used in planning included occurrence data for special elements, and remotely sensed abiotic and geoclimatic data. Habitat suitability models and population viability models were constructed for the focal species to guide choices on how much and which types of habitat should be included to conserve these species. Using simulated annealing (see Box 14.2), unprotected areas within the ecosystem that are biologically irreplaceable and vulnerable to degradation were identified.

Vulnerability was assessed using an expert assessment of multiple criteria, including the proportion of each unprotected area in private versus public ownership; presence of active grazing, mining, or timber leases or potential for such activities in the near future; road density and trends; human population and housing density and trends; and, disruptive recreational uses and trends. The irreplaceability of the unprotected areas was assigned using the following criteria, which were weighted equally:

- Protects at a minimum 50% (or 100% for critically imperiled globally or imperiled globally) of the viable occurrences of: imperiled local-scale species, vulnerable and declining birds, coarse scale and regional scale aquatic fish species, and plant communities.
- Represents, at a minimum, 25% of the area of each wetland vegetation type, and at a minimum 15% of the area of each other vegetation type in the region.
- Represents, at a minimum, 15% of the area of each geoclimatic class in the region.
- Represents 20% of the length of each aquatic (stream) habitat type in the region.
- Protects habitat capable of supporting 75% of the population of each focal species that currently could be supported in the region, as determined by the species distribution models.
- Maintains viable population of focal species over time, as determined by the population viability model.

Protecting the areas of highest irreplaceability and vulnerability would expand the reserve system by 22% and increase protection of threatened species by 46% and the representation of geoclimatic classes by 49%. The protection of these areas might be achieved through designating new, or extending existing, national parks, but could also be achieved through less strict protection measures such as conservation easements, management agreements, and national monument designations. Noss et al. (2002) proposed that the highest priority areas (those with highest irreplaceability and vulnerability)

BOX 14.2 Formulation of the Conservation Planning Problem for Designing Reserve Systems

The classic systematic conservation planning problems are to either maximize or minimize the value of an objective function to obtain desired coverage in a reserve system. These are simply expressed mathematically, and then solved by one of a number of methods.

Minimum-Set Problem

The objective of the minimum-set problem is to minimize the resources expended while meeting the conservation objectives.

Let each site have a cost c_j and each feature a conservation objective r_i . The variable x_j equals 1 if site j is selected for the reserve system, otherwise it equals 0. The representation of feature i in site j is contained in a matrix with elements a_{ij} . The objective is to minimize:

$$\sum_{j \in J} c_j x_j$$

subject to the equation:

$$\sum_{j \in J} a_{ij} x_j \geq r_i$$

for every feature i .

Specific versions of this general problem include varying the costs, varying the currency of the features' representation a_{ij} , and varying the objectives. For example, to minimize the number of sites needed to represent each feature, c_j equals 1, because the sites have equal size and/or equal cost; to minimize the total area needed to represent each feature at a particular level, the cost of a site c_j is its area; and to minimize the total cost needed to represent each feature at a particular level, the cost of a site c_j is its monetary value.

We may need to deal with different sorts of objectives for different features. Where we only have presence/absence data the variable a_{ij} equals 1 if feature i is in site j , otherwise it equals 0. In this case the target for that feature, r_i , equals 1, if a single representation of each feature is sought, and r_i is a number > 1 , if multiple representa-

tions of each feature are sought. If we wish to conserve a fraction of the area of a particular feature and the data, a_{ij} , represents the area covered by feature i in site j , then r_i should be the amount of habitat that we wish to conserve.

Maximal Coverage Problem

The objective of the maximal coverage problem is to maximize the level of feature representation given a fixed amount of resources.

For feature i in site j the objective is to maximize:

$$\sum_{i \in I} y_i$$

subject to:

$$\sum_{j \in J} c_j x_j \leq T$$

where c_j and x_j are as previously defined. If the conservation objective allocated for feature i is achieved y_i equals 1, otherwise it equals 0. The maximum available expendable resource is T , which is in the same units as c_j .

The methods for solving systematic conservation planning problems fall into several classes: local heuristic algorithms, which select sites in a stepwise manner (Pressey et al. 1993; Pressey et al. 1994), global heuristic algorithms, which select sites in sets (e.g., simulated annealing, Ball and Possingham 2000, 2001), and optimization algorithms (Cocks and Baird 1989; Underhill 1994).

Kirkpatrick (1983) was the first to define the minimum set problem and used a heuristic method to find the solution. An iterative **heuristic algorithm** iterates through a list of sites, choosing the best site at each step according to explicit rules (Nicholls and Margules 1993). The process implicitly considers complementarity, as the contribution of unselected sites to meeting the conservation objectives is recalculated each time a site is added to the reserve system.

A greedy heuristic algorithm adds sites to the reserve system sequentially by selecting the site that adds

the most unprotected species to the set that has already been selected. Therefore, it "greedily" attempts to maximize the rate of progress toward the objective at each step. With our example from the Cape Floristic Region described in the text, this algorithm would first select site 4 from Table 14.2 because it would protect nine species, and after that select either sites 1 or 6 as each would add three additional species. Regardless of whether site 1 or 6 is selected first, both will be selected. After that site 8 would be required. Therefore, four sites are required to form the minimum set. Note that sites 1, 4, and 6 do not form a very compact set. If we were concerned about fragmentation then we may want to find a different solution. An alternative algorithm is to represent those species that occur in only a handful of sites first (that is, represent the rare species first). For example, seven species are only represented in one site each. Sites 1, 4, 6 and 8 are essential to represent all of these species. A rarity algorithm first selects any sites that are essential and then selects sites that add the most unprotected species to the reserve system. Therefore, rare species are targeted first and a complementary set is built from there. However, local heuristic algorithms that choose sites sequentially are not guaranteed to find the optimal solution; indeed they are unlikely to find optimal solutions for anything but small problems.

An alternative approach is to express the conservation planning problem in the form of an integer linear program and use mathematical programming techniques to find the optimal solution (Cocks and Baird 1989; Church et al. 1996). However, integer linear programming may fail with large datasets and have the further disadvantage of producing only a single optimal solution and therefore not allowing for flexibility as a range of solutions is not provided.

Continued on next page

Box 14.2 *continued*

Global heuristic algorithms, such as **simulated annealing** and genetic algorithms, use some of the principles of local heuristics, but can allow us to make bad decisions in the short-term to improve the chances of getting better overall solutions. While they do not ensure that the optimal solution will be found, they are the most reliable and advanced method for large problems and facilitate flexible decision making by offering many very good solutions. Practically, this is what decision-makers need.

In the context of conservation planning, simulated annealing (Kirkpatrick et al. 1983) begins by generating a completely random reserve system. During each iteration, a site,

which may or may not be in the reserve system, is randomly chosen. The change to the value of the reserve system by adding or removing this site is evaluated. This change is combined with a parameter referred to as the “temperature” and then compared to a uniform, random number. The site is then added to or removed from the reserve system, depending on this comparison. When the temperature is high, at the start of the process, both good and bad changes are accepted. As the temperature decreases, the chance of accepting a bad change is lessened and eventually only good changes are accepted (Ball and Possingham 2000; Possingham et al. 2000). The acceptance of bad changes early

in the process allows the reserve system solution to move temporarily through suboptimal solution space. The advantage of allowing bad changes as well as good is that it can avoid getting trapped in local optima and increases the number of routes by which the global minimum might be reached, improving the chance of obtaining an optimal or near-optimal reserve system.

These methods to solve systematic conservation planning problems have been used in many places throughout the world to guide the design and expansion of reserve systems.

should receive the highest levels of protection, whereas lower priority areas could accommodate greater levels of human use.

Recent rezoning of the Great Barrier Reef represents another case where systematic conservation planning has aided decision-making. The Great Barrier Reef Marine Protected Area extends about 400 km outward from the coast for a length of over 2300 km along the north east coast of Australia (Figure 14.11). It is one of the largest marine protected areas in the world and is managed by a single Federal Government Agency—the Great Barrier Reef Marine Park Authority (GBRMPA).

On July 1, 2004 the Marine Park was rezoned, becoming the largest systematically designed reserve system in the world. From a scientific perspective the first step in the rezoning was to classify the reefs and the area between reefs into 70 “bioregions.” The different bioregions synthesize a large amount of expert opinion and biological data on the distribution and abundance of marine organisms. Each bioregion is sufficiently different from the other bioregions that a comprehensive reserve system needs to contain samples of every bioregion. Hence, a major goal of the rezoning was to conserve at least 20% of every bioregion in “no take” zones that prohibit extraction of marine resources for everyone, or all but traditional peoples. Further principles guiding the planning process included a minimum size for individual protected areas of about 400 km², replication of each bioregion in three separate protected areas, minimizing fragmentation, and ensuring geographic diversity to improve the representativeness of the reserve system.

Ultimately all of the principles, data, and socioeconomic information were combined to define various

reserve system options. MARXAN, freely available conservation planning software (www.ecology.uq.edu.au/marxan.htm), was used to integrate the biological principles with data on social preferences and economic information about uses of the region to provide a range of

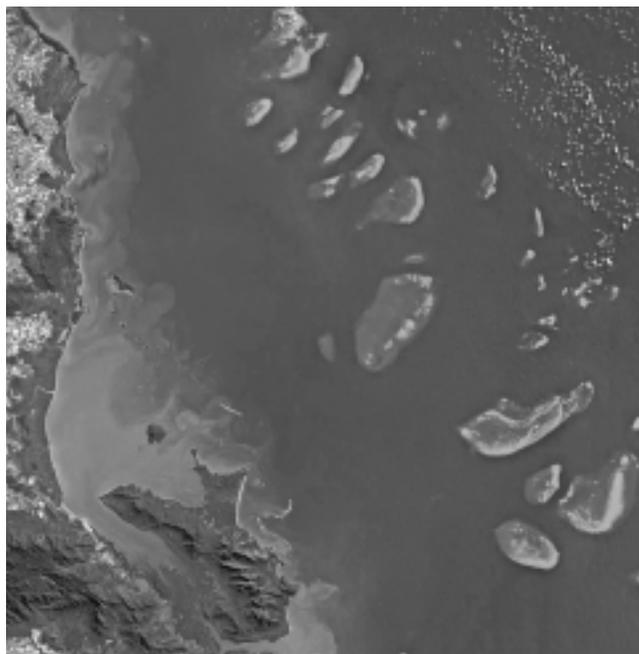


Figure 14.11 Great Barrier Reef is one of the most diverse areas on Earth. The Great Barrier Reef marine protected area extends over 345,400 km² and about one-third is newly protected from commercial fishing. (Photograph courtesy of NASA.)

plausible conservation options. These options were used by GRBMPA and the community to select a rezoning plan acceptable to the Federal Government. This is the largest scale and most complex application of systematic conservation planning principles and tools to date.

The Great Barrier Reef Marine Park is divided into eight zones, each of which allows different uses. In particular, the scientific research and marine national park zones do not allow more than traditional use of marine resources, and no extractive uses whatsoever (e.g., fishing) are allowed in preservation zones. Until 2004 less than 5% of the park was zoned no take and now about one third of the entire park does not permit commercial take. The conservation prospects for this remarkable region are certainly brightened by this outcome, while the abilities to use this productive ecosystem for a variety of human uses has been preserved.

Designing a reserve system for the Cape Floristic Region of South Africa

To understand systematic conservation planning, it is useful to overview the planning process in detail for a specific example—the Cape Floristic Region of South Africa (Cowling et al. 2003a). This area is recognized as a center of plant and animal diversity and endemism, and as a global hotspot of biodiversity (Cowling et al. 1996; Olson and Dinerstein 1998; Myers et al. 2000). The region is the world's smallest floral province, yet is home to many more indigenous plant species than any other similar-sized area, with 70% of its plant species found nowhere else on Earth. Moreover, the region is the most threatened of the world's six floral kingdoms (Rouget et al. 2003b), with 1406 threatened plant species (Cowling and Hilton-Taylor 1994). In total 30% of the region has been altered, with the major threats to biodiversity being cultivation, urban development, and the spread of non-native invasive trees (Rouget et al. 2003b). Protected areas in the region account for 22% of the land area and include both strictly and informally protected areas, however, these are biased towards upland areas (Rouget et al. 2003a). Cowling and Pressey (2003) outlined three major reasons why a systematic conservation plan was required for the region: (1) the existing reserve system did not represent biodiversity; (2) there were increasing threats to biodiversity; and (3) there was diminishing institutional capacity for conservation.

Systematically designing a reserve system for the Cape Floristic Region required several tasks and a large amount of biological and biophysical data. The first task was to delineate the geographical extent of the planning region, within which decisions would be made about the location, configuration, and management of protected areas. The planning region for the Cape study was centered on the Cape Floristic Region—an area of 87,892 km²; the region extends approximately 60 km beyond

the boundaries of the Cape Floristic Region to capture ecological processes that transcend this boundary.

The second task was to identify the elements of biodiversity requiring protection in the planning region. These elements, referred to here as features, can include species, populations, species assemblages (for example, vegetation types), land classifications (for example, environmental classes), and features that represent important natural processes. In the Cape Floristic Region, data for five different kinds of biodiversity features (Cowling et al. 2003a) were used to develop the systematic conservation plan:

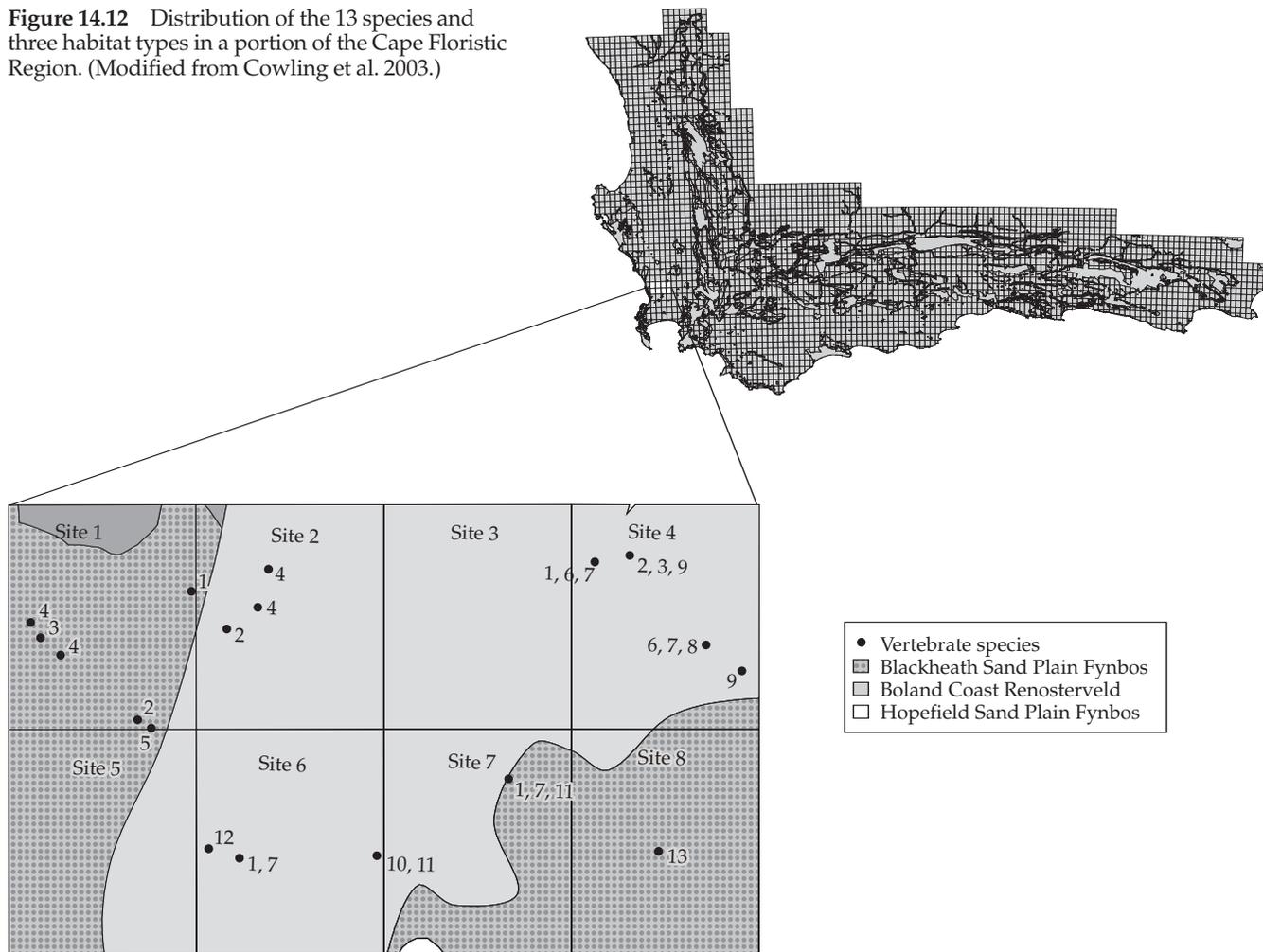
1. Land classes
2. Plant species in the family Proteaceae
3. Selected lower vertebrates (i.e., fishes, amphibians, and reptiles)
4. Large- and medium-sized mammals
5. Features important for ecological and evolutionary processes (for example, edaphic interfaces and macroclimatic gradients)

The Cape Floristic Region study was one of the first systematic conservation plans to incorporate a large variety of features, in particular, **ecological process features**.

The third task was to delineate the geographical units of evaluation, referred to here as planning units. Planning units can be any discrete part of the landscape and any size or shape, including rectangular or hexagonal grids cells, ownership parcels, vegetation types, sub-catchments, vegetation fragments, or logging compartments. Information on the occurrence or extent of each feature within each planning unit is required; for example, how much of a particular land class is in the unit and whether or not there is a record of a particular species. In the Cape Floristic Region study, the planning unit layer was a grid of sixteenth-degree squares (approximately 3900 ha each; Figure 14.12) (Cowling and Pressey 2003). The existing protected areas were also used as planning units because they contribute to conserving features; however, it was assumed that the existing protected areas were fixed and they were themselves not considered candidates for selection. The boundaries of ecological process features (e.g., edaphic interfaces and riverine corridors) were incorporated as process planning units. The planning unit layer for the Cape Floristic Region consisted of 3014 grid cells (74.5% of the region), 2993 process planning units (6.2% of the region), and 1032 protected areas (19.3% of the region).

The fourth task was to generate conservation objectives, which are in the same units employed to record the occurrence or extent of each feature in each planning unit. Each feature may be given its own objective to reflect its ecological requirements, natural rarity, or vulnerability to threatening processes; otherwise, a generic

Figure 14.12 Distribution of the 13 species and three habitat types in a portion of the Cape Floristic Region. (Modified from Cowling et al. 2003.)



objective can be assigned to all features (e.g., conserve 20% of each vegetation type). The development of conservation objectives for the Cape Floristic Region is described in Pressey et al. (2003).

Planning in the Cape Floristic Region relied heavily upon expert knowledge to derive many of the data layers, for example the land classes, mammal distributions, and the spatial distribution of threats. This would be true in any region, even where the region is well studied and the data are abundant. Expert knowledge was also used in the final stages of deriving the conservation plan (Cowling et al. 2003b).

The conservation plan sought to achieve some minimum representation of biodiversity features for the smallest possible cost (a minimum set problem: see Box 14.2). Therefore, the objective was to minimize costs and biodiversity protection entered as a constraint. This is best illustrated by an example taken from the larger data set. Here, for a sample of thirteen species and three habitat types, the objective is to conserve at least one popula-

tion of every species and at least one representation of each habitat type. The presence or absence of each of the 16 features is known for eight sites as illustrated in Table 14.2 in a site-by-features matrix (see Figure 14.12 for an illustration of the distribution of the species and habitat types). The minimum set problem is to find the smallest number of sites that will represent every species once. A "1" denotes a presence of either a species or habitat type, and a "0" denotes the absence of either a species or habitat type. In this case, the minimum set reserve system is sites 1, 4, 6 and 8 as no other set of sites will conserve all species.

While this solution can be calculated by hand, for bigger datasets this would be impossible. For example if there are 5000 sites, the number of possible reserve systems is 2^{5000} . Therefore, methods have been devised for searching for the minimum set that represent efficient solutions to reserve system design problem (see Box 14.2). Such a computer-aided approach was used in this case.

TABLE 14.2 An Example of a Site by Features Matrix for the Cape Floristic Region

Species number	Feature	Sites								Species/habitat range
		1	2	3	4	5	6	7	8	
1	Ocellated gecko (<i>Pachydactylus geitje</i>)	1	0	0	1	0	1	1	0	4
2	Sand toad (<i>Bufo angusticeps</i>)	1	1	0	1	0	0	0	0	3
3	Cape caco (<i>Cacosternum capense</i>)	1	0	0	1	0	0	0	0	2
4	Cape sand frog (<i>Tomopterna delalandii</i>)	1	1	0	0	0	0	0	0	2
5	Clawed frog (<i>Xenopus laevis laevis</i>)	1	0	0	0	0	0	0	0	1
6	Cape legless skink (<i>Acontias meleagris meleagris</i>)	0	0	0	1	0	0	0	0	1
7	Karoo girdled lizard (<i>Cordylus polyzonus</i>)	0	0	0	1	0	1	1	0	3
8	Marico gecko (<i>Pachydactylus mariquensis mariquensis</i>)	0	0	0	1	0	0	0	0	1
9	Common caco (<i>Cacosternum boettgeri</i>)	0	0	0	1	0	0	0	0	1
10	African leaf-toed gecko (<i>Afrogecko porphyreus</i>)	0	0	0	0	0	1	0	0	1
11	Cape girdled lizard (<i>Cordylus cordylus</i>)	0	0	0	0	0	1	1	0	2
12	Common egg-eater (<i>Dasyplettis scabra</i>)	0	0	0	0	0	1	0	0	1
13	Delalande's beaked blind snake (<i>Rhinotyphlops lalandei</i>)	0	0	0	0	0	0	0	1	1
	Blackheath Sand Plain Fynbos	1	1	0	1	1	0	1	1	6
	Hopefield Sand Plain Fynbos	1	1	0	0	0	0	0	0	2
	Boland Coast Renosterveld	1	1	1	1	1	1	1	1	8
Site species/habitat richness		8	5	1	9	2	6	5	3	

The final conservation plan for the Cape Floristic Region covered 52.3% (49,958 km²) of the extant habitat in the planning region (Figure 14.13). The conservation plan was developed in a series of stages and built upon existing statutory protected areas (stage 0). The first stage incorporated planning units for four spatially fixed process components (edaphic interfaces, upland-lowland interfaces, sand movement corridors, and inter-basin riverine corridors). The second stage incorporated planning units of maximum irreplaceability for achieving the conservation objectives for broad habitat units, plant species in the Proteaceae, and vertebrate species. The third stage incorporated planning units for achieving the conservation objectives for large- and medium-sized mammals. The fourth stage planning units were selected to represent macroclimatic gradients, and the fifth stage considered upland-lowland gradients. The final stage of the planning process involved selecting planning units to achieve all outstanding conservation objectives for broad habitat units, endemic plants in the family Proteaceae, and vertebrates, while minimizing the inclusion of highly vulnerable areas (Cowling et al. 2003a).

Confronting Threats in Protected Areas

As described throughout this chapter, conservation planning involves locating and designing protected areas to promote the persistence of biodiversity in situ. Therefore, protected areas must be able to mitigate at least some of the processes that threaten biodiversity. Information on threatening processes and the relative vulnerability of areas and natural features to these processes is therefore crucial for effective conservation planning.

Pressey et al. (1996) defined vulnerability as the likelihood or imminence of biodiversity loss to current or impending threatening processes, and this definition can be extended to distinguish three dimensions of vulnerability: exposure, intensity, and impact (Wilson et al. 2005). Exposure is either the probability of a threatening process affecting an area over a specified time, or the expected time until an area is affected. Areas with the same exposure to a threatening process can be affected at different levels of intensity. The intensity of a threat can take many forms, such as the volume of timber extracted per ha of a forest type or the density of an invasive plant species. Impact refers to the effects of a threatening

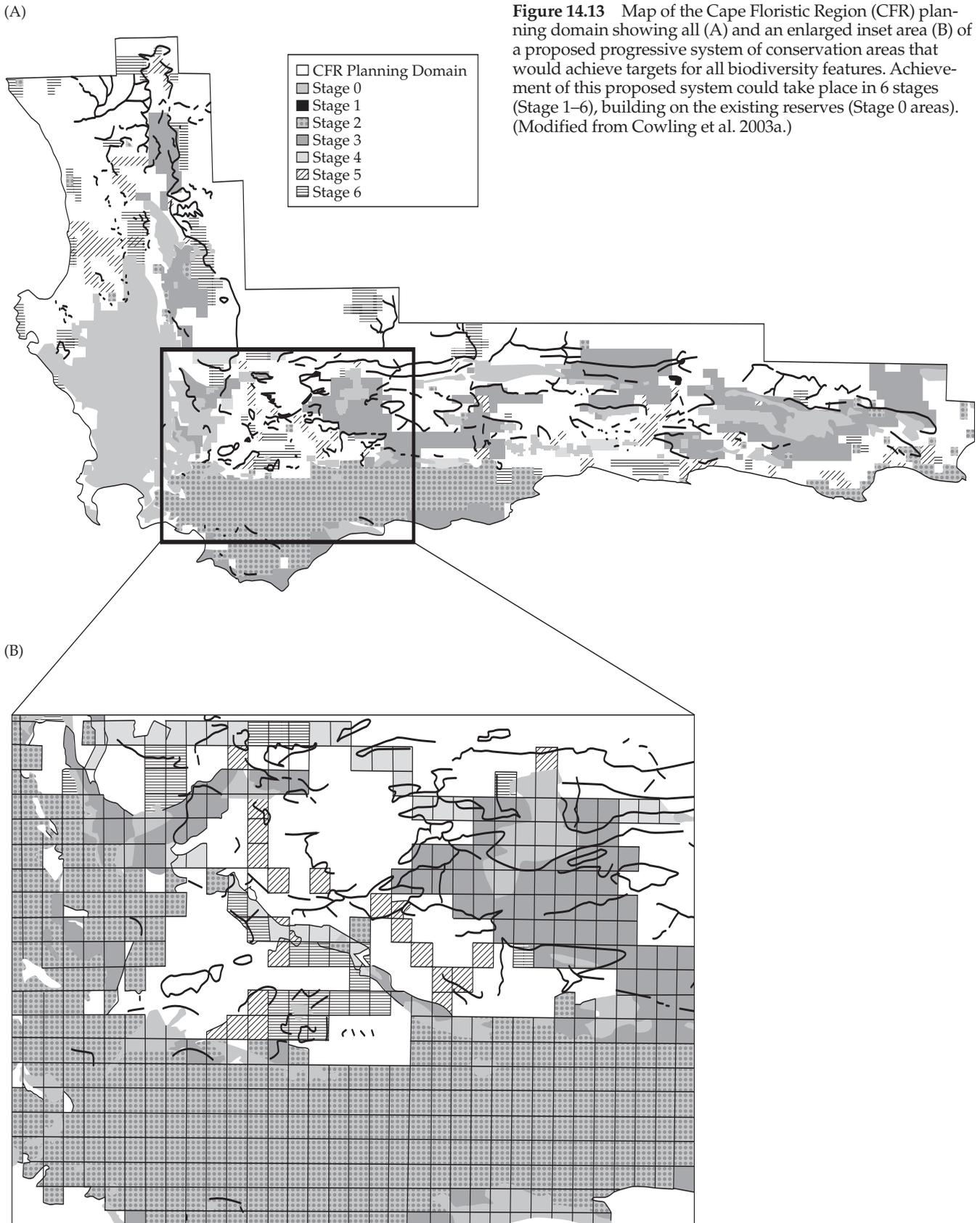


Figure 14.13 Map of the Cape Floristic Region (CFR) planning domain showing all (A) and an enlarged inset area (B) of a proposed progressive system of conservation areas that would achieve targets for all biodiversity features. Achievement of this proposed system could take place in 6 stages (Stage 1–6), building on the existing reserves (Stage 0 areas). (Modified from Cowling et al. 2003a.)

process on particular features and could indicate effects on distribution of species, their abundance, or likelihood of persistence. Areas of particular concern for conservation planners have high exposure to very intense threatening processes. Features of concern will be those occurring in such areas and experiencing strongly negative impacts.

Wilson et al. (2005) review methods that have been used to assess vulnerability and categorized them into four groups based mainly on the types of data employed. All methods estimate exposure, but some deal also with intensity and impact. The first method uses information on permitted or projected land uses. The second method identifies the extent of past impacts on features and uses these data to predict future impacts on the same features. In some circumstances, the underlying spatial (e.g., proximity to cities and roads) and environmental characteristics (e.g., soil type, slope, climate) believed to have predisposed areas to threatening processes in the past are determined, and areas that are presently unaffected and share these characteristics are then identified. The third method identifies vulnerable areas as those with high concentrations of taxa with high probabilities of extinction, and the final method is based on expert knowledge. All four methods have been employed at a variety of spatial scales and resolutions in countries with differing levels of development, even in those typically regarded as data-poor. The data underpinning many of the methods are globally available and so most methods are applicable anywhere, at least at a coarse scale.

When developing a conservation plan, vulnerable areas might be avoided so that objectives are achieved, as far as possible, in areas without liabilities for implementation and management. Considerations of defensibility, or avoiding vulnerable areas, can be especially important if resources are likely to be insufficient for effective management (Peres and Terborgh 1995). When implementation of new protected areas commences, an important consideration in scheduling their implementation will often be their relative vulnerability. The more vulnerable areas might receive higher priority, especially if there are few or no alternative areas available to protect the features they contain (Pressey and Taffs 2001; Noss et al. 2002; Lawler et al. 2003). This strategy can minimize the extent to which conservation objectives are compromised by threatening processes during the frequently protracted process of establishing protected areas on the ground.

Protected areas can be important in mitigating proximate threats arising from activities such as agriculture, logging, mining, or grazing of domestic livestock. In some cases, and depending on resources for management, protected areas can also prevent or reduce the spread of non-native plants and animals and mitigate the adverse effects of changes to fire regimes and other natural disturbances.

However, protected areas might be ineffective in excluding invasive nonnative plants and animals or mitigating hydrological impacts from nearby developments unless complemented with intensive on-site management and changes in land-use patterns throughout the region. Given the limitations of protected areas in preventing all threats to biodiversity, conservation planning must operate as part of a broader conservation strategy involving policy, legislation, education, and economics.

Conservation objectives and persistence

Conservation plans are most often formulated to represent biodiversity pattern, where pattern might be measured, for example, by the distribution of species or habitat types. More recently, attempts have been made to improve the likelihood that biodiversity persists in protected areas by setting conservation objectives for viability (Noss et al. 2002) and natural processes (Pressey et al. 2003), and by considering spatial design (McDonnell et al. 2002).

While conservation objectives (such as conserving 15% of a remaining habitat type) are politically expedient and have generally helped to grow the global reserve system, these objectives are general and do not recognize that some regions will require significantly higher levels of protection than others. Even though the goal of protecting 10% of the terrestrial world has been surpassed, the global reserve system is far from complete in terms of conserving global biodiversity (Rodrigues et al. 2004a,b; Hoekstra et al. 2005). In addition to using blanket area objectives, we may also need species-based and ecoregion-based objectives that will better encompass the spatial distribution of biodiversity, need for protection, and other factors, such as levels of endemism and rarity.

Dynamics and uncertainty

In the context of extensive and increasing threats to biodiversity, theoretical and procedural advances in conservation planning over recent decades (such as those described in Box 14.2) have been important but insufficient to guide the investment of limited resources for conservation. A major shortcoming is that, while there is a considerable body of theory and procedures for designing reserve systems in a static world, there is limited theory for their design in a dynamic world.

Static approaches to conservation planning assume that proposed protected areas can be acquired instantly and that these areas will remain unchanged prior to protection. In the "real world," the process of identifying and implementing reserve systems is rarely instantaneous and even if an "optimal" reserve system can be identified and prioritized, budget and opportunity constraints may mean that it takes decades of negotiation and land purchases to translate a conservation plan into

a functioning reserve system (James et al. 2001; Pimm et al. 2001). In the interim, the acquisition of proposed protected areas might be hindered and the areas may undergo changes. Some biodiversity might be lost and some areas may be destroyed or degraded before they are acquired. Others may no longer be available for conservation. Changes in the political and economic climate may also constrain conservation action. These problems highlight another source of complexity in conservation planning: the existence of uncertainty.

Meir et al. (2004) have considered the consequences for conservation planning of assuming a static world and ignoring uncertainty. They found that using relatively simple rules for selecting areas to be protected, such as choosing the available area with the highest species richness or the highest richness of rare species, worked better than designing optimal reserve systems, particularly in the context of land-use change and uncertainty affecting where opportunities for conservation investments might arise. Although the performance of optimal sets (see Box 14.2) and comprehensive conservation plans will undoubtedly improve if the plans are iteratively updated, they found that, given the rates of habitat loss reported in the literature, comprehensive conservation plans would need to be updated annually to perform as well as the simple decision rules. Because information contained within conservation data bases is updated relatively slowly, and it takes a considerable amount of work to develop comprehensive conservation plans, updating these plans annually seems unrealistic. Thus, conservation resources might be better invested in determining the biodiversity value and relative importance of particular sites, rather than in developing comprehensive designs for large-scale systems of protected areas. In Case Study 14.3, Gustavo Kattan discusses the difficulties of applying conservation planning tools when biological information is very sparse, as it is in the Andes region of Colombia.

Despite the contribution of recent work that has improved reserve system planning, it is recognized that there is room for further developments. The development of theories and procedures for undertaking conservation planning in a dynamic and uncertain world is an active area of research.

Complex economic considerations

The conservation principle of efficiency incorporates some economics into conservation planning, however, there are a complex range of economic issues that require further consideration. Often these are considered through cost-benefit analyses, as described in Chapter 5. Here we explore just a few additional ways that economics could play a greater role in conservation planning, but there remain many unanswered questions and

unsolved problems at the interface of biodiversity conservation and economics.

First, most of the conservation planning literature ignores the impact of protected area dedication on areas outside the reserve system. For example, in the marine realm closing areas to fishing may only serve to displace that fishing effort to other areas, making a once sustainable industry, unsustainable. In the terrestrial realm, all acquisition of property affects local property prices. Consequently, acquiring areas for protection can reduce the cost-effectiveness of future additions to a reserve system.

Second, much of the conservation planning literature focuses on the cost of acquiring a reserve system, ignoring the cost of maintaining the biodiversity values for which the protected areas were acquired. More sophisticated conservation planning theory should account for both the initial cost of purchase and the long-term maintenance of the protected area, including all the uncertainties inherent in protected area management.

Finally we need to recognize complex trade-offs between the different values society places on different types of land use. The classic conservation planning problems (see Box 14.2) of minimizing costs while reaching all conservation objectives, or maximizing biodiversity benefits for a fixed cost allow no trade-offs between biodiversity and economics. In each case one of the two currencies is set as a hard constraint and the other currency is maximized (or minimized). Trading between different societal values, however, occurs all the time. Hence, theories and tools for making such trade-offs are needed. The need becomes even more pressing when we consider other values of landscapes, such as amenities, water filtration, and soil protection. Ultimately economists can play an active role in helping determine how society would like to trade-off between these different values by incorporating nonuse values into planning analyses (see Chapter 5).

Incorporating Social and Cultural Contexts

Over the past few decades, we have greatly advanced our technical capacity to design effective reserve systems. Yet, sound systematic conservation planning cannot ensure the success of a protected area or a reserve system if it does not account for the social and cultural context of a region. Currently, between 300 and 420 million people live in a state of chronic poverty globally (Adams 2004). How we reconcile biodiversity protection goals with the needs of hundreds of millions of the world's poor requires careful consideration.

The modern model of federally-owned and managed protected areas has its roots in the nineteenth century

movement for national parks in the U.S. In the U.S., clearly delineated boundaries that demarcate wilderness areas from areas that can be logged and a management focus towards enforcing restrictions on human use or interference might be politically appropriate. The problem with applying this model without consideration of the social and cultural contexts is that communities living near newly created protected areas may be denied access to the resources that form the basis of their livelihoods. Furthermore, it may be impossible to enforce a method of border demarcation or use restrictions that are not part of the cultural context of a region. For example, in Papua New Guinea, where a complicated land tenure system controls access to resources, agreements to protect an "area" must be based on use of the resource, not a line on the ground.

While conservation planning is important, in the end, protected area boundaries will be largely influenced by social and political factors. Thus, consideration of the history of an area is not an esoteric issue but an important element for gauging its likelihood of success as a protected area. How boundaries are defined when protected areas are established and what features they include, as well as land tenure rights within and surrounding protected areas are thus issues of tremendous importance in ensuring effective conservation and management of biodiversity. Governments, nongovernmental organizations, multinational corporations, local peoples, and funding agencies may all influence success.

The case of Amboró National Park, Bolivia illustrates the problems that may arise when a protected area is established without proper consideration of, or consultation with, local communities (Moreno et al. 1998). Amboró National Park ranges from the humid zone of the Andes mountains to the dry area of the Chaco to the east. The site was first designated as a natural reserve in 1973, but this declaration did not include a management plan, nor did it restrict or change local use of the area. Resource extraction and human settlement continued. In 1984, however, the reserve was reclassified to national park status. With the elevated status came new management objectives that prohibited hunting and fishing and the extraction of timber. Forestry concessions were annulled and all existing within-park settlements were subjected to restrictions. Then, in 1991, the government of Bolivia issued a decree expanding Amboró from 180,000 to 637,000 ha, more than tripling its initial size.

The expansion of the Amboró was celebrated by conservationists as it incorporated watersheds and ecosystems that were previously unrepresented. However, the government's expansion of the protected area was performed without regard to social factors, an analysis of

existing land tenure, and consultation of the communities residing in or around the park (see Case Study 12.2). Existing human settlements were incorporated by the expansion, thus implicitly contradicting national law that prohibits resource use in protected areas. The incorporated communities and people living nearby became hostile to the park for having usurped their lands and their rights to its use. It was soon recognized that the current exclusionary management of the park was unsustainable. In an attempt to reduce tension over the new park boundaries, a program was initiated to negotiate new zones for internal protection of the park, after community consultation (Moreno et al. 1998).

This program, termed the Red Line Project, involved community members clearing a 1.5 m wide path that would represent the limits of their use rights within the park. This visible boundary helped reinforce differences in uses allowed outside, rather than inside, the park. In certain areas the project moved forward and raised hope that the new line would come to constitute the new park boundaries. In other areas a stalemate occurred because park administration and local people could not agree over boundaries, as some communities claimed land deep inside the park.

In spite of Bolivian law disallowing resource use in national parks, intense use continued inside of Amboró in areas where Red Line agreement could not be reached. Deforestation resulting from slash-and-burn agriculture and small-scale timber extraction continued, along with hunting. The land tenure situation and means of initial establishment of the park made it unlikely that resource use would cease. In 1996, a decree was issued to reduce the size of Amboró to 440,000 ha. While this could be seen as a loss to conservation, the history of the Park's formation made it inevitable that its conservation goals would fail. Albeit a smaller protected area than it once was, resource extraction inside the park has been reduced and improved management is helping the park successfully meet its current biodiversity conservation goals (Moreno et al. 1998).

The case of Amboró illustrates the importance of considering social and political factors in conservation planning. While conservation objectives and reserve design goals should inform siting of protected areas, achieving a successful protected area necessarily will be tied to social and political context.

The vast majority of regions where protected area expansion is most urgent are in low-income, tropical countries that can least afford the costs of establishing and managing new reserves (Bruner et al. 2004). The majority of the benefits of protected areas are realized at the global scale, even if we include long-term local benefits. Thus, the costs of establishment of protected areas in priority regions largely should be borne by the glob-

al community. Financing on behalf of the global community may be done through multi and bilateral institutions, foundations, private corporations, and individuals. While the task of global coverage will be challenging, protected areas are highly cost-effective when

it comes to protecting biodiversity. Advances in data availability coupled with advances in the science of conservation planning are allowing us unprecedented opportunity to move forward with the urgent task of conserving biodiversity.

CASE STUDY 14.1

Conservation Management of a European Natural Area

Doñana National Park, Spain

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In contrast to the Americas, Europe has been settled by technological western cultures for thousands of years, and these people have had a long time to leave their mark upon the land. Consequently, fewer natural areas remain in Europe than in many other regions, and there are fewer opportunities to manage them in a semi-pristine state. The challenges of managing the remaining natural areas are great, as the relatively small remnants exist in a matrix dominated by humanity. This phenomenon is not unique to Europe—indeed, many protected areas in densely populated regions face many challenges, and as human populations continue to grow, this phenomenon will become more common.

Doñana National Park of Spain serves a critical role in biodiversity conservation, and is embedded in a matrix of high human use. Doñana is unique in many respects; it is a major stopover point in the migration route of birds moving between Europe and Africa, it is home to some of the most endangered mammals in the world, and it contains perhaps the most significant wetland in Europe. Despite thousands of years of use, Doñana remains one of the most ecologically important sites left in the midst of lands wholly or mostly converted to human uses. Yet Doñana's ability to support biodiversity is under constant threat due to its proximity to culturally and economically critical locations in Spain. In this case study, I will explore the importance of this national park, historically and ecologically. As I discuss the external and internal challenges to the protection and management of Doñana, I will build perspective of what is necessary for protecting its future.

Location and Description of Doñana National Park

The 50,720 ha Doñana National Park, located in Andalucía on the southwestern coast of Spain (Figure A), is part of the Guadalquivir River Basin. The Guadalquivir is one of the largest rivers in the country and is the only navigable one. The area has a subhumid Mediterranean climate, influenced by the Atlantic Ocean, with alternating dry and rainy seasons (Em-

berger et al. 1976; Font 1983; Siljeström et al. 2002). Some three thousand years ago, during the pre-Roman period, a lake (Lacus Ligustinus) covered much of the area (Rodríguez and Clemente 2002a). The lake remained during Roman colonization until approximately the fourth or fifth Century A.D., after which the progressive appearance of a littoral bar (Rodríguez and Clemente 2002a) and alluvial deposits due to severe deforestation in the uplands transformed the lake into a marsh with a tidal influence, and ultimately into a marsh with a pluvial influence (Bernúes 1990; Rodríguez and Clemente 2002b). It is on this marsh that most of present-day Doñana National Park is located.

Doñana has three dominant ecosystem types: fixed dunes (or "cotos"), mobile dunes, and marshes (Montes et al. 1998). The fixed dunes are affected by the depth of the water table, the mobile dunes are driven by substratum mobility, and the marshes are created by seasonal rains (García-Novo et al. 1977). The mobile dunes, which run parallel to the coastline for 30 km, are the most important dunes on the Iberian Peninsula and some of the most extensive in Europe. They move an average of 4–6 m per year, with some sections moving up to 20 m per year (García-Novo et al. 1976). The marshes occupy some 27,000 ha, and are highly productive and seasonally variable, with winter water depths up to 1 m and little to no water during summer. The broad ecotone between the marshes and uplands has a complex vegetational structure and a high faunal diversity, including many herbivores and predators.

The Biogeographical Importance of Doñana

Doñana's geographical position, between the European and African continents and between the Atlantic Ocean and the Mediterranean Sea, results in a rich flora and fauna, with some 838 species of vascular plants, 39 species of fishes, 11 amphibians, 21 reptiles, 370 birds, and 29 mammals recorded. The park is especially critical to bird diversity, as some three-fourths of all European species are found in Doñana due to its position on the migratory routes of many species and its abundant food re-

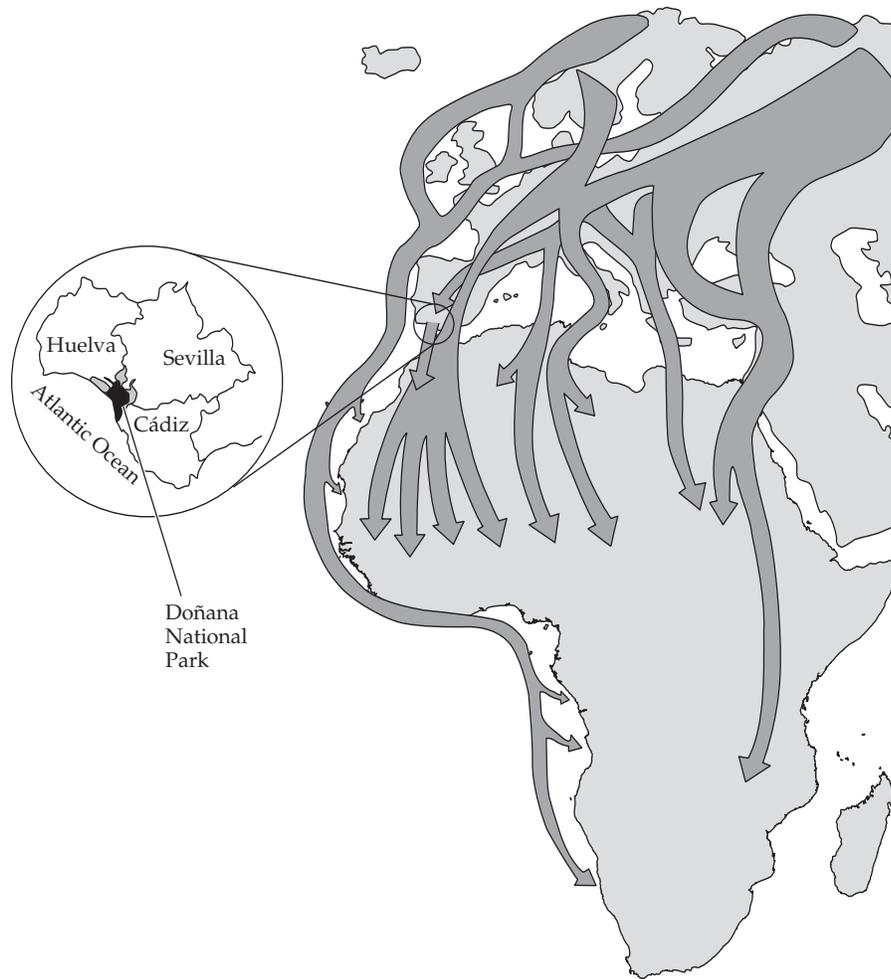


Figure A Doñana National Park is located in a critically important area of southern Europe on the Iberian Peninsula. Major bird migration pathways for the entire European and African continents pass through Doñana.

sources (see Figure A) (García-Novo et al. 1977; Amat 1980; Máñez and Garrido 2002). During spring and autumn migration, it is easy to observe more than 200 species of birds.

Many Doñana species are endemic, threatened, endangered, or otherwise of ecological interest. This includes an endemic cyprinodontid (*Aphanius baeticus*) recently described as a new pupfish species (Doadrio et al. 2002), the White-headed Duck (*Oxyura leucocephala*), European Bittern (*Botaurus stellaris*), Squacco Heron (*Ardeola ralloides*), Marbled Teal (*Marmaronetta angustirostris*), Ferruginous Duck (*Aythya nyroca*), Crested Coot (*Fulica cristata*), Andalusian Hemipode (*Turnix sylvatica*), Curlew (*Numenius arquata*), Black Tern (*Chlidonias nigra*), Ruddy Shelduck (*Tadorna ferruginea*), Slender-billed Gull (*Larus genei*), Spanish Imperial Eagle (*Aquila adalberti*), Purple Gallinule (*Porphyrio porphyrio*), the only European species of mongoose (*Herpestes ichneumon*), and the Iberian lynx (*Lynx pardinus*), considered by the IUCN (2004) as the most threatened felid in the world.

This rich natural area means that Doñana is one of the most important wetlands in Europe. This was recognized when it was declared a national park by the Spanish Government in 1969, a wetland of international importance by the Ramsar

Convention, an International Biosphere Reserve in 1981, and a World Heritage Site by UNESCO in 1995.

Human History in Doñana

Human habitation and use of the Doñana area goes back 3000 years B.C. (Rivera 2002). All the great European civilizations have passed through and used this area, including Tartesics, Phoenicians, Greeks, Romans, Visigoths, and Arabs. Prior to 1262, the area was controlled by Arabs, and the marshlands were used for grazing by Arabian horses, while the surrounding hills were used for timber extraction and wax and honey harvesting from beehives. In 1262, after conquering the area, the Christian King Alfonso X established a hunting area in Doñana, beginning a hunting phase that lasted 400 years (Granados 1987). Hunting centered on wild pigs and red and fallow deer in the forest, and on waterfowl in the marshes. This activity largely protected the forest, which served as a shelter for game species. However, hunting encouraged the eradication of predator species such as foxes, wolves, birds of prey, lynx, and mountain cats. There were large rewards for each animal killed, which greatly reduced the predator populations, while the herbivore populations, freed of their enemies, increased considerably.

In 1628, the introduction of cattle began a new phase in Doñana (Granados 1987). In addition to cattle grazing, people were able to cut firewood for their personal needs. Excessive cattle populations resulted in overgrazing, reduced the Doñana cork oaks (*Quercus suber*), and increased dune formation. Growing interest in forest development led to a forestry phase. Initially, forestry was centered on cork oaks, white and black poplars, willows, ashes, and junipers (Granados 1987). Many animal species that were unable to adapt to the changes were locally extirpated, including the Black Stork (*Ciconia nigra*) and the Swan (*Cygnus* sp.). Forestry activity increased with the introduction of pines in 1737, which was so successful that they are the principal component of the forest today, with a resulting loss of oaks.

In approximately 1940, river red gum (*Eucalyptus camaldulensis*) was introduced in many areas of the park. The purpose of this introduction was to produce cellulose for pulp and paper companies. The species, a native of Australia, withdraws great amounts of soil nutrients and lowers the water table due to its fast growth and excessive transpiration; it also has allelopathic effects on other vegetation and contains highly flammable volatile oils, which can trigger forest fires in hot and dry seasons (FAO 1985). An eradication program continues today to eliminate residual specimens. Introduction of this invasive species and other agricultural activities represent the largest human intervention in Doñana in recent years. Aside from river red gum, an additional 50 plant species were introduced both accidentally and intentionally; most of these, however, became scarce because of inappropriate conditions and low soil fertility.

Modern scientific interest began in the 1950s, with expeditions led by the Spanish naturalist José A. Valverde. The area was eventually visited by renowned naturalists such as Guy Mountfort, Roger Tory Peterson, and the Nobel laureate Sir Julian Huxley, which raised its public visibility. During that time, Doñana was seriously threatened by government forestry and agricultural initiatives, and Valverde asked for help from many international organizations (IUCN, International Wildlife Research Bureau, International Council for Bird Preservation). As a result of these activities, in 1964 the World Wildlife Fund (WWF) helped a Spanish scientific group buy 6794 ha in the Doñana area, establishing the first protected area, the Doñana Biological Station. In 1969, Doñana National Park was officially created with an initial extension of 37,425 ha; this was enlarged to 50,720 ha in 1978 when the present boundaries were established. In 1989, the regional government declared 53,709 ha surrounding the park as protected area, designated the Doñana Natural Park, ushering in the present conservation phase. Together the national and natural park constitute one of the most important in the European Continent, with nearly 40,000 ha of pristine marshes, more than 5000 ha of rivers, ponds, channels, and lagoons, 7000 ha of coastal and sand dunes, 43,000 ha of coniferous forests and 24,000 ha of shrublands (Figure B).

Conservation and Management Problems in Doñana National Park

The Doñana National Park and Natural Park areas are affected by tremendous pressures from all sides. Despite the large total size of the protected area, these external and internal threats require active management.

External problems

In the present conservation phase, human activities within the boundaries of Doñana have drastically diminished, and its traditional uses have begun to be managed. Most of the problems are now external. One of the biggest conflicts centers on agriculture. The beginning of the conservation phase coincided with recent agricultural development of lands surrounding Doñana. Until that time, most of the marshlands of the Guadalquivir estuary were, from an agricultural perspective, unproductive; however, with advances in agricultural technology, these impoverished soils were improved. Large hydraulic works built to improve agriculture in areas around Doñana directly influenced water flow within the park. Natural canals have been cut, blocked, or transformed depending on the particular interest surrounding each. Presently, strawberry and flower cultivation in the so-called Almonte-Salt Marsh Sector extracts groundwater for irrigation. There is even a 1000 ha rice field which uses 10 hm³ of ground water. All these activities are lowering the water table, thus threatening the park's vegetation (Rodríguez and Clemente 2002b). In the last 30 years groundwater extractions have reduced stream flow in the area to about 50% of historic flows (ITGE 1999). This process is altering the hydrological dynamic of the marshland, increasing the length of the dry period. Other negative impacts are the accumulation of agricultural plastic waste residues and contamination of surface waters with pesticides and excess nutrients. Some areas are still being deforested to allow for new cultivation.

On April 25, 1998 part of the dike of a tailings pond at the "Los Frailes" zinc mine, located in Aznalcóllar collapsed. The accident released about 4 million m³ of acidic water and 2 million m³ of mud rich in toxic metals to the Guadiamar River, the lower tributary of the Guadalquivir, whose waters flow into Doñana (Grimalt and Macpherson 1999; Borja et al. 2001). As a consequence, 67 km of the Guadiamar main channel and 4634 ha of the floodplain were polluted with heavy metals, particularly Fe (34–37%), S (35–40%), Zn (0.8%), Pb (0.8%), As (0.5%), and Cu (0.2%) (Grimalt et al. 1999). The avalanche of water and sludge was stopped just before Doñana National Park, thanks to the rapid construction of an emergency dam.

Cleaning efforts continued until the summer of 2000 and constituted an unprecedented effort that removed more than 98% of the sludge. Nevertheless, mechanical removal of the contaminants increased the negative effects of the toxic spill by causing major impacts on geomorphological characteristics of the area (Gallart et al. 1999). Most of the studies on the flora and fauna conducted after the accident showed that pollution

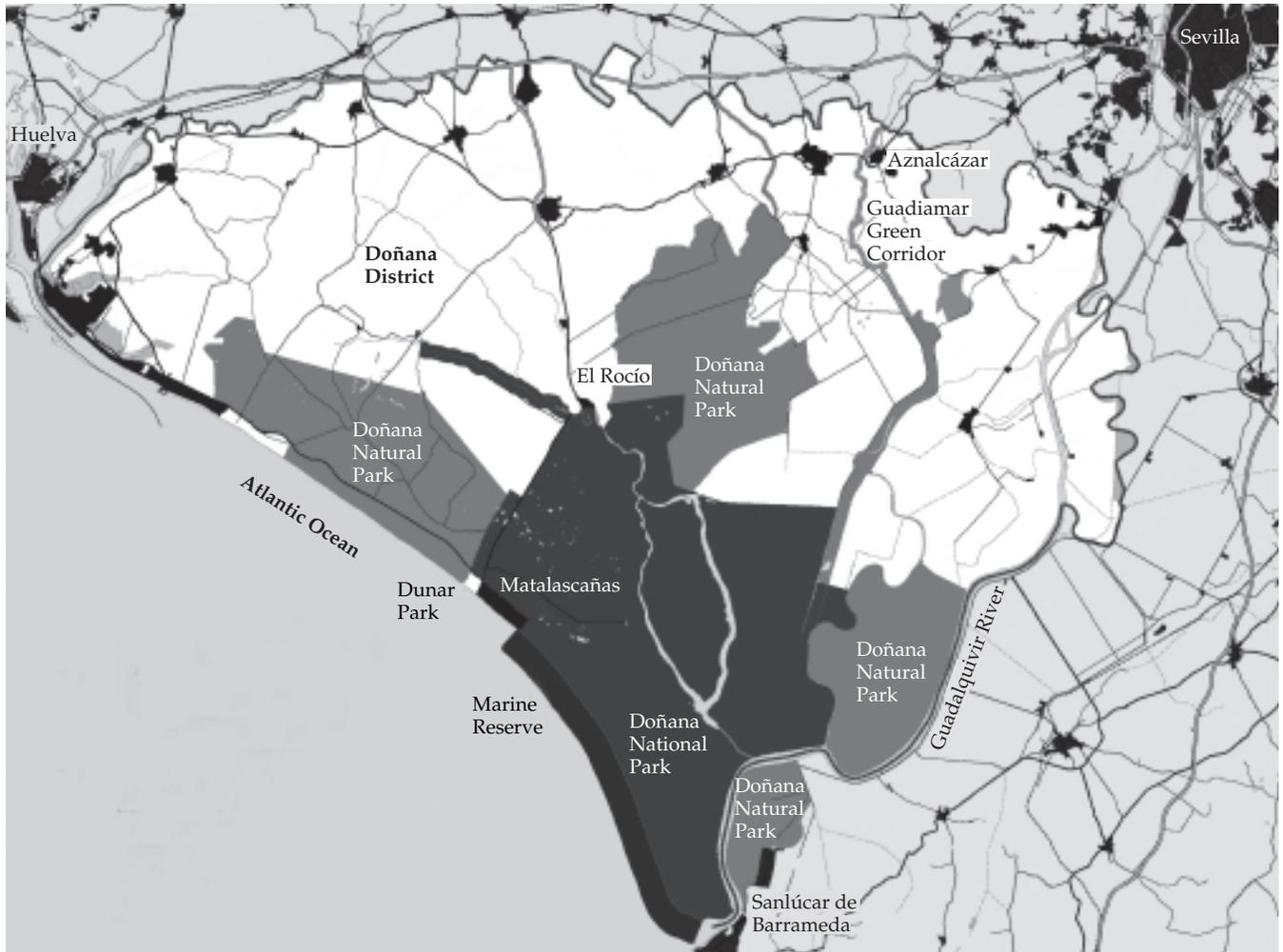


Figure B Doñana National Park is surrounded by the Natural Park, both included in the so-called Doñana District, a larger area which includes 14 villages and some 150,000 residents. Distributed in different villages and natural areas of the National and Natural parks are 8 visitor centers, 7 observatories, 2 research centers, 4 other natural areas, 6 recreation areas, and many hiking, biking, and horse trails. (Modified from Plan de Ordenación del Territorio 2002.)

did not seriously affect the trophic web in Doñana (Junta de Andalucía 2003). However, those zones of the mine devoted to processing raw materials have not been cleaned and the large areas where the old tailing deposits are located have not been restored. All of this will make the mine a long-term source of contamination, perhaps for centuries. The accident also demonstrated the vulnerability of Doñana and the problems involved with the management of a natural area if the whole ecosystem is not considered.

Aside from agricultural and heavy metal residual contamination, waters are also polluted with organic contamination coming from the neighboring villages (the majority of their waste water has not been purified) (Arambarri et al. 1996; Arribas et al. 2003). Pollutants arriving to Doñana have caused fish and bird mass mortality; 50,000 and 20,000 birds were

killed in 1973 and 1986, respectively (Castroviejo 1993, Arribas et al. 2003; Saldaña et al. 2003).

Matalascañas, an old fishing village on the beaches of Doñana, has become a major urbanized tourist area with about 80,000 people visiting each summer. Major impacts of tourism include lowering of the water table, coastal organic pollution, and straying of domestic animals into the park. Political pressures for new urbanized areas are constant. Ultimately this pressure has led to a modification of one of the main conservation programs for Doñana (Plan for Territorial Direction of Doñana Area of 1988) to allow the construction of a major urbanized area in Sanlúcar de Barrameda, close to Doñana (Figure C).

Since the 1960s there has been a great demand for new roads within Doñana to promote tourism. Thus, numerous roads have been built, which has improved transit through the

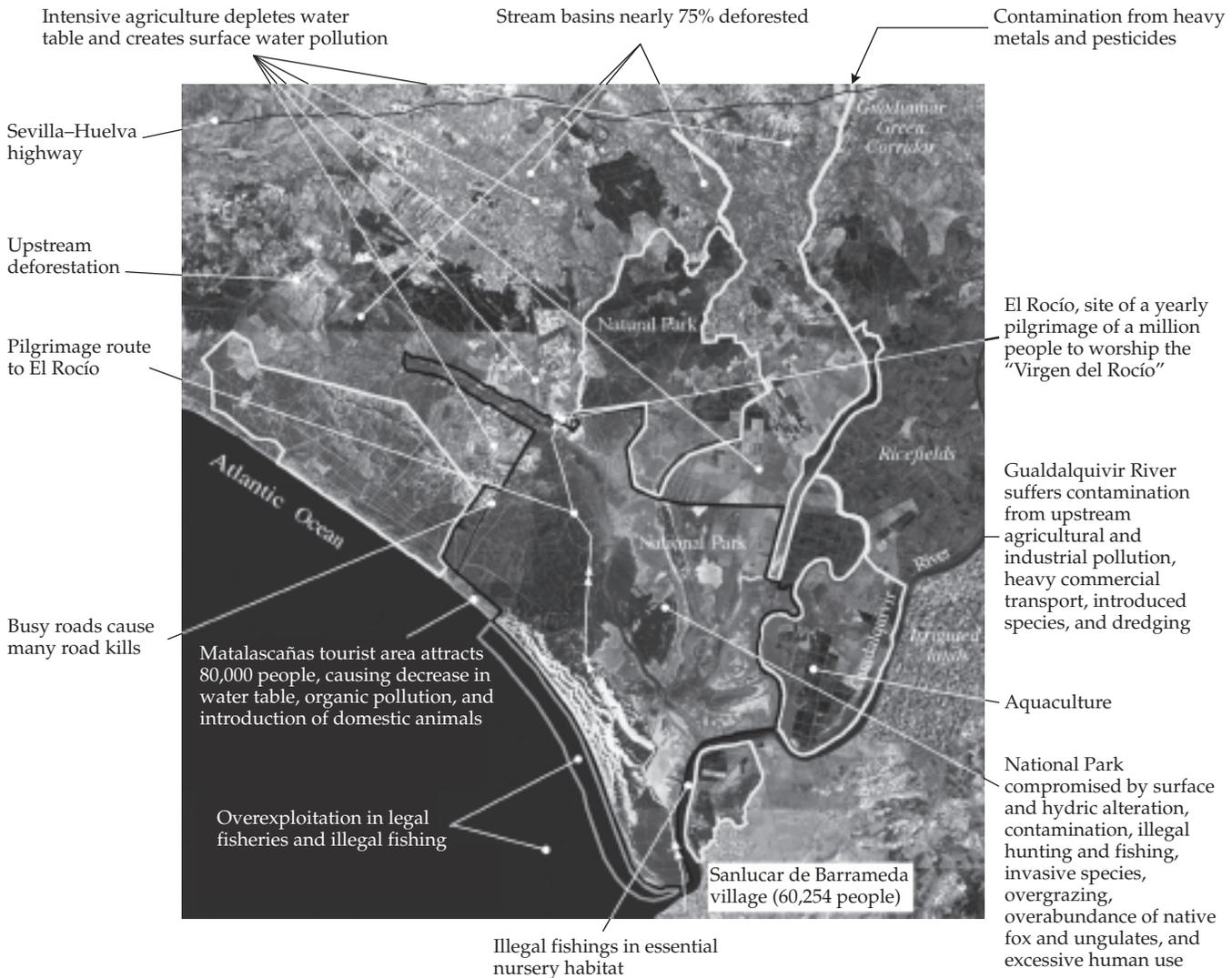


Figure C A schematic overview of the many conservation problems facing Doñana National Park. (Modified from Junta de Andalucía 1995.)

park (see Figure C). However, roads fragment habitats and are a primary source of mortality for many Doñana vertebrates. Almost 50% of all lynx mortality in the area is due to automobiles (Ferrerías et al. 1992; Ramos and Soriguer 2002). In 2002, a rural road passing through one of the best habitats for Doñana's lynx was asphalted; two lynx have subsequently been killed by cars. This is significant for this species, as there are no more than 200 individuals in the wild, of which 30 are living in Doñana (Guzman et al. 2002).

Another negative impact on Doñana National Park has its origin in the cultural aspects of the area, especially in a religious tradition centered in the nearby village of El Rocío, where pilgrims have gathered annually since the sixteenth Century to celebrate the Virgin of Rocío. Initially this was a local celebration, but today it is a national event, with the number of visitors (called "romeros") increasing every year. The

pilgrimage, or "romería," is a festival lasting one week, during which more than 1 million visitors arrive in a variety of vehicles, including nearly 250,000 horses. A diversity of groups or, "brotherhoods," use traditional roads to get to the village, one of which crosses the National Park from south to north (see Figure C). More than 10,000 people and 3000 vehicles use this road twice a year. One of the biggest problems is that this activity takes place during one of the most delicate times of year in the National Park, during spring, when many birds are breeding. Elimination of this traditional activity is not possible due to traditional rights and the strong public outcry and revolt that it would engender. Nevertheless, strong regulations are increasing every year under the so called "Plan Romero."

Hunting has increased considerably in areas around the park because of the large numbers of birds that are attracted to Doñana. Nevertheless, since the Aznalcóllar accident, hunting

was forbidden in the surrounding areas and restrictions continue in some of them. Predators are also attracted to the park, and adjacent landowners set illegal traps or poison them; this is a leading cause of death for many carnivores, including the Imperial Eagle and the lynx (Estación Biológica de Doñana 1991). Illegal fishing in the lower reaches of the Guadalquivir River is damaging an important nursery area for fisheries in the Gulf of Cádiz. Considered an important biodiversity hot spot for the aquatic communities (Fernández-Delgado et al. 2000), many are particularly concerned by these activities.

Navigation in the Guadalquivir River toward the port of Seville constitutes another environmental problem due to riverbank erosion as well as continuous dredging to deepen the navigation canal. At this time, there is a large project to extract about 10 hm³ of sediments to deepen the navigation canal to increase the numbers of vessels going to Seville. The project has been approved by the Spanish Environmental Minister (Boletín Oficial del Estado 2003) in spite of the protest of scientific and conservation groups. A second project to construct a large dam in the Guadalquivir River near Doñana, which could destroy the entire estuarine ecosystem (Fernández-Delgado 1996) has been temporarily delayed.

In addition to the increase in maritime traffic activity in such a sensitive ecological area, there is also an increased risk of introduction of species transported in ballast water or on the hulls of vessels (Carlton and Geller 1993; Ruiz et al. 2000). Several invertebrate species have already been introduced by this process (Cuesta et al. 1991, 1996; Fernández-Delgado 2003), including the Chinese Mitten Crab (*Eriocheir sinensis*) an invasive species that has severely impacted the San Francisco Estuary in California (Aquatic Nuisance Species Task Force 2002). At this time the Seville Port Authorities have not addressed this problem.

Finally, capacity of dams built in the Guadalquivir river basin reach 7000 hm³; this could increase salinity intrusion in the estuary and decrease productivity of the area due to nutrient retention. In addition to these predictable effects is possible alteration of the trophic dynamics of the whole estuarine ecosystem.

Internal problems

Inside Doñana there are also problems. Deforestation of the stream basins surrounding the National Park has increased erosion, generating siltation and sand deposition problems in some areas. Thus, 350 ha of marshlands have been inundated with sand coming from the El Partido stream.

The red and fallow deer populations are overabundant and from time to time must be controlled artificially. Nevertheless, the greatest damage on the terrestrial vegetation is from the 5000 cows and horses living inside the national park. Many areas in Doñana are affected by this cattle pressure (Soriguer et al. 2001). Local people have traditional rights to use the pastures, and park managers have had only limited success regulating the number of cattle inside the park. Another problem is

that they are passing diseases such as tuberculosis to wild mammals (Ramos and Soriguer 2002).

Foxes and wild pigs are also very abundant and difficult to control because of their high reproductive rates; the density of foxes in Doñana is one of the highest in Europe (Rau 1987), which has fatal consequences for rabbit populations already affected by introduced viral infections (myxomatosis and the hemorrhagic viral disease). Reduced rabbit populations directly affect the Imperial Eagle and lynx populations inside the park, which rely on rabbits as primary prey (Ramos and Soriguer 2002). The eagle has decreased from 15 pairs in 1976 to nine at present (Ferrer 1993; Reserva Biología de Doñana 2002). There are some 30 lynx living in Doñana, and only five of these are mature females (Ramos and Soriguer 2002).

Botulism, an endemic illness in Doñana affecting waterfowl, may become a major problem if water quality declines further (INITAA 1992), a likely event considering the low water quality entering the marshlands (Castells et al. 1992; Saura et al. 2001). The accumulation of heavy metals and pesticides, especially in birds of prey, threatens to reduce their reproductive success (González et al. 1984; Hernández et al. 1986, 1988; RBD 2002). Illegal hunting and fishing are also problems in spite of the large number of guards controlling the national and natural parks.

Most of the water management in Doñana has been oriented toward waterfowl; thus, many sluices were built in the past to prevent fresh water from flowing from the park into the Guadalquivir River. This activity has isolated the various water bodies of the park from the main river, preventing fishes and aquatic invertebrates from colonizing after a dry period. The number of fish species inside the national park (17) is much lower than outside (46), with some of them critically endangered.

Nonnative invasive species have markedly changed the ecology of Doñana. The most spectacular effect has been due to the intentional introduction of the red swamp crayfish (*Procambarus clarkii*) in 1974. This species is so well adapted to the area that it has not only altered trophic relationships, but has also influenced the economy of the region (Montes et al. 1993). Diversity and biomass of the macrophyte community has also been negatively affected by this species (Duarte et al. 1990; García-Murillo et al. 1993). Presently, the crayfish occupies nearly all of the Iberian Peninsula, and annual harvest in the Doñana area is 2700–4300 metric tons.

The water fern (*Azolla filiculoides*), an invasive aquatic pteridophyte, threatens the marshland ecosystem (Cobo et al. 2002). Six (35%) of the 17 fish species living in Doñana are nonnative. Carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) reduce water quality. The eastern mosquitofish (*Gambusia holbrooki*) and the mummichog (*Fundulus heteroclitus*), threaten the endemic pupfish (*Aphanius baeticus*) with near extinction (Fernández-Delgado et al. 2000) just as largemouth bass (*Micropterus salmoides*) contributed to disappearance of the stickleback (*Gasterosteus aculeatus*) (Fernández-Delgado 1987).

The most recent fish colonization is by the pumpkinseed (*Lepomis gibbosus*), which has stable populations inside the park (Fernández-Delgado et al. 2000). In 1999, the Florida turtle (*Trachemys scripta*) was detected in some water bodies of Doñana (Díaz-Paniagua et al. 2002).

Measures to Protect Doñana

At this time, four programs are being developed to protect both the National and Natural Parks, one focused on the national park (The Use and Management Plan of the Doñana National Park), two on the natural park (The Ordination Plan of Natural Resources of the Nature Park, and The Use and Management Plan of the Nature Park) and a fourth on the Doñana region (The Coordination Territorial Managing Plan of Doñana and their Surroundings).

Conservation measures within the park fall under "The Doñana National Park Management Plan" (Boletín Oficial del Estado 1991), which are currently being updated. This plan is implemented by a committee of people who represent local, regional, and national governments, universities, citizens, and conservation associations. The committee's guiding philosophy is that conservation takes priority over any other activities within the park, and that the park's natural richness depends on conservation in the surrounding areas.

The park has been divided into four zones: Zones of Special Use (173 ha), which include installations for park management and visitor information centers, Zones of Moderate Use (382 ha) intended to preserve the traditional roads that cross the park, Zones of Restricted Use (100 ha) near the information centers, where people are allowed to walk freely, and Reserve Zones (50,065 ha), the bulk of the park, with entry restricted to managers, researchers, landowners, and other authorized people.

The program is designed for management of natural resources, research, public use, compatible extractive uses, and improving the relationship between the park administration and its neighbors. Included in the natural resource management plan is an attempt to restore the park's water system to its state before the transformations adjacent to Doñana. Managers are also trying to maintain and/or recover the vegetation formations characteristic of Doñana by eliminating exotic species, controlling animal plagues and illnesses, and by preventing fires.

Both the flora and fauna of Doñana are managed toward preservation of native species, protection of threatened or endangered populations, control of overabundant species, and elimination of nonnative species where possible. Two management programs focus on the most visible and charismatic species of Doñana: the lynx and the Imperial Eagle. Both programs are oriented toward habitat improvement, which will benefit many other species as well. Additionally, densities of ungulates (red deer, fallow deer, wild pigs) and foxes are being controlled, and the most abundant introduced plants are being eradicated.

The management plan allows the park's use by local residents for traditional resource extraction, such as coal mining, beekeeping, harvest of mollusks (*Donax trunculus*) on the beach, and of pinecones in the forest, hunting and fishing in designated areas, and extensive cattle grazing. A public use program provides visitors with information about the national park and argues for the need for its conservation. Seven reception centers have been built at various points to inform visitors of Doñana's history and natural riches.

A series of outreach activities is attempting to improve the relationship between the national park and the residents of surrounding areas. These activities include environmental education programs in the neighboring villages; information points about the park have been established in several of them.

The 53,709 ha of Doñana Natural Park is managed by the regional administration through the Ordination Plan of Natural Resources of the Nature Park and The Use and Management Plan of the Nature Park in Seville. Both plans work together to manage all the activities in this buffer area compatible with the conservation of the national park. As that of the national park, the plans are run by a committee of people representing local, regional, and national governments, universities, communities, and conservation associations. The natural park is divided into three parts; Reserve Zones (10.5%) include natural areas with high natural values. These areas are exclusively devoted to conservation, research, education, or ecological restoration. Special Use Zones (74.5%) represent areas with high natural values but with some degree of human intervention. The activities here are oriented to preserve the system through the sustainable use of resources. Finally, there are the Common Regulation Zones (15.0%), modified areas of light-moderate use that have some natural interest. Here, conservation measures are oriented to the development of restoration and management programs, which try to reduce the impact of human activities.

There is a fourth plan called the Territorial Regulation Plan for the Doñana district. Its main objective is to establish the jurisdictional basis for the regulations and sustainable development of the surrounding Doñana areas (see Figure C) to secure and make compatible the preservation of the natural resources with socioeconomic progress and the increment in the quality of life of their people. The area affected includes 14 villages with about 150,000 people and has a budget of some U.S.\$40 million for the next 12 years.

The Future of Doñana

Two questions remain. Will Doñana ultimately be saved from the human pressures that surround it? And what will be its conservation status when it passes to the next generation?

At the end of the 1980s, Doñana had serious conservation problems. Conflicts increased between conservation of the natural areas and increase of economic activities, especially with the expansion of strawberry cultivation, tourist areas, and ur-

banization projects. Inside the park there were also many problems with the local people relative to traditional uses of resources. Local people felt that the national park was delaying economic development of the area. This led to the President of the Regional Government to create an International Committee to evaluate the situation, identify the problems, and suggest solutions (Castells et al. 1992). The report set the basis for the development of "The Sustainable Development Plan for Doñana's Neighboring Areas," the first plan of this type in Spain. The plan foresaw an investment of some U.S.\$350 million between 1992 and 2000 to develop economic activities in the surrounding villages compatible with conservation goals of the national park. The funds came from the European Union (59%) and the Regional (36%) and Central (5%) governments. Only 10% of the European funds came specifically for the plan; the rest were monies previously adjudicated to the Regional and Central administrations and that were redirected to this plan (Requejo and Belis 2003). The Doñana 21 foundation (see: <http://www.donana.es/index.php>) was created to develop the plan. Ten years later, this plan has been evaluated through the Doñana+10 Foundation (see: <http://www.donana-mas10.com>). The majority of this investment has been for water management (23%), equipment and road infrastructure (31%), agriculture (11%), and environment (18%). The rest paid for a variety of programs such as education (6%), tourism (4%), and promotion of economic activities (6%) (Belis et al. 2003). Unfortunately, even with this investment 13% of the objectives were not met, and some of them, such as the agriculture and water management programs, clearly failed. The most successful were road construction, tourist infrastructures, and enterprise opportunities.

To the advantages associated with the Sustainable Development Plan for Doñana's Neighboring Areas we have to add the improved quality of life for the people of the Doñana region in recent years. The rent per capita is now similar to the rest of the Andalucía Region. Between 1991 and 2001 unemployment decreased by 42%. The number of enterprises increased from 400 to 800 in 10 years and in the last 30 years the population has grown 30% (Junta de Andalucía 2002). This process is driven by agriculture, mainly strawberry cultivation, which now covers about 4000 ha in the lands surrounding the national park.

Because of these developments and the Aznalcóllar toxic spill, two big restoration programs are being conducted in the region: the Guadiamar Green Corridor and the Doñana 2005

Restoration Program. The former, promoted by the Regional Government, aims at restoration of the Guadiamar basin and reestablishment of an ecological corridor between the mountainous area of Sierra Morena and the littoral systems of Doñana. At the same time, the program seeks improvement of the quality of life of Guadiamar basin inhabitants by developing a socioeconomical system that is environmentally sustainable and integrated into the natural context. It had a budget of about U.S.\$40 million for 1998–2001 with a research program of U.S.\$7 million in the subsequent five years. The program is in line with the European Water Framework Directive because it covers the whole riverine system and strives to preserve the natural dynamics of the riverine ecosystems.

The second program, funded by Spain's Ministry for Environment, promotes the restoration of large degraded areas. It aims at the hydrologic regeneration of the watershed and river bed flowing into the marshland of the national park to recover the water supply to the marshlands, ensure quality and quantity of water, and stop wetland degradation. The project is the most important wetland restoration effort ever undertaken in Spain, both for its budget (U.S.\$129 million) and for the extent of its target area.

The number of publications about Doñana have increased sharply in the last few years, and the system is better known, which is good for conservation. Several museums have been opened (Sea World Museum, Religious Museum) and new natural areas have been acquired for public use, such as the Dunar Park (see Figure B). At this time in the Doñana region there are eight visitor centers, seven observatories, two research centers, six recreational areas, six horse trails, six bike trails, seven hiking trails, and four jointly coordinated nature reserves. This infrastructure led to more than 400,000 visitors to the area in 2002. On the other hand, one the most successful aspects of the Doñana sustainable plan has been a decrease of aggressiveness toward the national park and development of a perception by the local people that Doñana represents a positive natural heritage that still has not been efficiently exploited, especially relative to tourism opportunities (Belis et al. 2003). Thus, in spite of the many challenges to Doñana, there are also many indications that it will be saved, though much work remains. A focused collaboration between central and regional governments, more active local participation in environmental decision making processes, more expert technical advice and, of course, more funding, are basic ingredients needed to preserve this important natural heritage.

CASE STUDY 14.2

The California Channel Islands Marine Reserves Scientists Informing Policy and Management

Satie Airame, University of California, Santa Barbara and Deborah Brosnan, Sustainable Ecosystems Institute

Marine Protected Areas (MPAs) have become an increasingly important tool for conserving coasts and oceans. MPAs are areas of the ocean where some or all activities are limited or prohibited to protect natural and cultural resources. MPAs have different shapes, sizes, and management characteristics, and have been established for different purposes. There are now well over 4200 MPAs worldwide and hundreds more are in the planning stages (Kelleher et al. 1995; Roberts et al. 2003). Their size spans over six orders of magnitude ranging from the very tiny (0.002 km²) to very large (846 km²; Halpern 2003).

Marine reserves (also known as “no take” zones) are a special class of MPAs in which an area of ocean is completely protected from all extractive and destructive activities. There is abundant evidence that protecting areas of the ocean in no take marine reserves leads to rapid increases in abundance, size, biomass, and diversity of animals that are fished or impacted indirectly by fishing, regardless of where in the world reserves are located. Halpern (2003) reviewed 76 studies of reserves that were protected from at least one form of fishing. Across all reserves, abundance (measured as density) approximately doubled. Biomass, or the weight of all organisms combined, increased 2.5 times in reserves as compared to fished areas. Average body size of organisms protected in marine reserves increased by approximately 30%. The increase in size contributes to greater reproductive potential (Béné and Tewfik 2003). In addition to changes in biomass, abundance, size, and reproductive potential, the number of species in each sample increased by 30%. However, marine reserves will do little to protect ocean life against external threats and influences such as climate change and pollution. Additional legislation and agreements will be needed to address these issues.

Marine reserves can be contentious because they limit consumptive activities, such as recreational or commercial fishing. The proposal of a marine reserve elicits strong emotions and responses in many people, including both those who feel that their livelihood or traditional way of life will be affected and those who believe that marine reserves are necessary to stop degradation of marine ecosystems.

Many early MPAs were created on the basis of common sense rather than on science; the underlying assumption was that some protection was better than none. In fact, many early MPAs that were designed for protection and conservation still allowed fishing and other extractive practices within their boundaries.

Scientific input is an important and necessary component of the design, implementation, and monitoring of MPAs world-

wide. MPA science continues to evolve as practical experience and research provide new insights and information. For instance, scientists have made important advances in how to meet multiple goals such as combining the protection of biodiversity (which argues for few large reserves) with fisheries goals (which favors many small reserves; Hastings and Botsford 2003). Scientists also have contributed knowledge on site selection (e.g., Airame et al. 2003; Roberts et al. 2003; Leslie et al. 2003), dispersal and genetics (e.g., Palumbi 2003; Shanks et al., 2003), and reserve size and spacing (e.g., National Research Council 2000).

The California Channel Islands Marine Reserves

In 1998, the California Fish and Game Commission, a state-appointed board with the authority to establish marine reserves, received recommendations to create no-take marine reserves around the northern Channel Islands off the coast of California (Figure A). Local environmental organizations, some fishing groups, and other concerned stakeholders—many of whom were alarmed by declines in fished species—developed a proposal for establishing marine reserves around the islands. However, because the broader community was not involved in its development, the proposal was rejected and a process was



Figure A The northern Channel Islands off the coast of California. (Photograph © Gary Crabbe/Alamy.)

established to bring together social, economic, and ecological information to support the decision about the marine reserves.

The process was developed by the California Department of Fish and Game, the state agency charged with managing fisheries and enforcing fishery regulations within California state waters (0–3 nautical miles offshore), and the Channel Islands National Marine Sanctuary, a federal agency that manages an area of 1252 square nautical miles of ocean around the northern Channel Islands of San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara. The sanctuary was established in 1980 to protect the region from oil and gas drilling. However, commercial and recreational fishing are allowed in the sanctuary, as long as the activities comply with regulations established by state and federal fisheries agencies.

Together, the California Department of Fish and Game and the Channel Islands National Marine Sanctuary began a community-based process to consider the appropriateness of marine reserves within the Sanctuary waters. To support the process, a Marine Reserves Working Group (MRWG) was established to represent the full range of community perspectives, including commercial and recreational fishing interests, diving and other nonconsumptive interests, and the general public. The MRWG worked together toward consensus using professional facilitators, and agreed on a set of goals (Table A) for the marine reserves. The MRWG met monthly for nearly two years to receive, consider, and integrate information about marine reserves and their potential role in the management of the Channel Islands.

The Channel Islands National Marine Sanctuary Advisory Committee (SAC) determined that decisions should be based on the best available scientific and socioeconomic information. Thus, the SAC established two advisory panels to assist the MRWG. A team of economists and social scientists was appointed to gather and evaluate socioeconomic data, and a panel of 16 marine scientists—the Science Advisory Panel (SAP)—was formed, including marine ecologists, oceanographers, ichthyologists, phycologists, fishery managers, geneticists, statisticians, and modelers. The SAP was asked to perform four tasks: (1) gather and evaluate information about marine reserves and

their effects; (2) determine the status and trends of marine species and habitats in the study region; (3) develop ecological design criteria for marine reserves; and (4) generate and evaluate options for networks of marine reserves. For over two years, the SAP worked closely with the MRWG to provide them with scientific advice. The process proved to be a challenge. Not only did scientists have to cope with limited scientific information, they also had to deal with challenges and criticisms from those opposed to marine reserves (or the inclusion of certain sites recommended by the scientists as important for protection).

At the same time, the public was active and vocal with their opinions. The California Department of Fish and Game and the Channel Islands National Marine Sanctuary received close to 10,000 public comments via email, faxes, phone calls, and letters. 94% were in favor of marine reserves and 6% opposed them. Many of those opposed wanted the size of proposed reserves reduced while many in favor thought that a greater extent—at least 30%–50% of the coastal areas—should be set aside as reserves. Moreover those opposed to the establishment of marine reserves frequently questioned the quality of the science and the biases of the scientists who served on the SAP. The scientists, who worked hard to ensure the quality and objectivity of their research, were not fully prepared for the strength and vigor of public criticism of the science and the scientists themselves.

Ecological Criteria for the Channel Islands Marine Reserves

To meet goals for biodiversity conservation, marine reserves should include each distinct biogeographic region in the study area (Roberts et al. 2003). A biogeographic region is an area of animal and plant distributions having similar or shared characteristics throughout. Three main biogeographic regions were identified in the Channel Islands waters based on biological and physical differences: a region of cool water to the northwest, a region of warm water to the southeast, and a zone of mixing between the two bodies of water. The SAP recommended setting aside several reserves within each of the three distinct biogeographic regions.

TABLE A *Marine Reserves Goals for the Channel Islands National Marine Sanctuary*

Category	Goal
Ecosystem and biodiversity	To protect representative and unique marine habitats, ecological processes, and populations of interest in the Channel Islands National Marine Sanctuary
Sustainable fisheries	To achieve sustainable fisheries by integrating marine reserves into fisheries management
Socioeconomic	To maintain long-term socioeconomic viability while minimizing short-term socioeconomic losses to all users and dependent parties
Natural and cultural heritage	To maintain visitor areas and spiritual and recreational opportunities which include cultural and ecological features and their associated values
Education	To foster stewardship of the marine environment by providing educational opportunities to increase awareness and encourage responsible use of resources

Source: Marine Reserves Working Group.

Conserving biodiversity also requires protection of a range of marine habitats within each biogeographic region (Roberts et al. 2003). The scientists developed a simple multidimensional habitat classification, using depth, exposure, substrate type, dominant plant assemblages, and other features. Their goal was to ensure that a suitable amount of each habitat was protected within each biogeographic region.

To conserve biodiversity, marine reserves should protect species of special concern, including keystone species, species of economic importance, and threatened and endangered species. The MRWG identified 119 species of special concern in the Channel Islands, including plants, invertebrates, fishes, seabirds and marine mammals. For species whose distributions were known, such as marine mammals and seabirds, the scientists used data to help locate potential sites for marine reserves. Fisheries data were used in a separate economic impact analysis to evaluate potential costs of reserve designs (Leeworthy and Wiley 2000).

One of the most important questions related to reserve planning is how much area should be in reserves. Ideally, the size of a marine reserve depends on the potential dispersal distance, population growth rate, and fishing pressure on species of special concern (Roberts et al. 2001). However, this information was not known for the majority of species of interest and therefore, the SAP followed more general guidelines. For conservation of biodiversity, the benefit of a reserve increases with size (e.g., Margules et al. 1988; Dayton et al. 2000; Roberts and Hawkins 2000). Larger reserves protect more habitats and populations, providing buffers against losses from environmental fluctuations or other natural factors that may increase mortality rates or reduce population growth rates. For fisheries management goals, however, the benefit of a reserve does not increase directly with the area it occupies. The maximum benefit of fully protected reserves for fisheries, in terms of sustainability and yield, occurs when the reserve is large enough to export sufficient larvae and adults, and small enough to minimize the initial economic impact on fisheries. After reviewing of the literature, the SAP recommended a wide range of possible reserve sizes, from 30% to 50% percent of the Channel Islands National Marine Sanctuary, to achieve both conservation and fisheries goals of the MRWG.

The SAP also addressed the important question of whether the marine reserves should be concentrated in a few large areas, or more spread out among a greater number of smaller areas. In the ocean, the ecological connections between different geographic locations can be much greater than on land because animals can drift and swim through the ocean with few barriers to movement. For example, larvae may drift at sea for several months as plankton, move as juveniles into shallow areas near the shore to grow, and settle as adults in deeper waters. Consequently, scientists developed the concept of networks of marine reserves (Roberts et al. 2001). A network of marine reserves is a set of marine reserves connected by larval dispersal and juvenile or adult migration (NRC 2000). Networks include reserves that may perform different functions,

such as providing nursery, spawning, and feeding areas. The conservation goals for a network of marine reserves are achieved through the combined effects of each reserve.

Applying Ecological Criteria to the Design of a Marine Reserve Network

Once they identified the ecological criteria, the scientists' next task was to apply the criteria to develop a variety of network designs for consideration by the MRWG. The scientists used a computer-based modeling tool known as MARXAN to evaluate the data and identify areas that could be effective marine reserves. To begin the process, the scientists divided the planning region, and associated data, into 1500 "planning units" of 1×1 minute (approximately 1×1 square nautical miles) following lines of longitude and latitude. The scientists entered the ecological criteria into the modeling tool. Then, the SAP used simulated annealing to explore and generate options for networks of marine reserves.

First, the program randomly generated an initial reserve system, made up of a set of planning units, including the target percentage of each habitat and feature. The program then calculated the "cost" of the reserve system based on the total size of the set of planning units. The program then randomly selected a planning unit and evaluated the impact of adding or removing it from the reserve system. This process continued a million times until a set of good solutions was produced. The ultimate goal of the process was to identify a solution that met the ecological criteria (in the form of a network of marine reserves) in the smallest area possible (to minimize the social and economic costs). At the end of the analysis, the SAP presented the MRWG with the ecological criteria used to run the model, the original data used in the model, and a portfolio of ten different options for networks of marine reserves.

The MRWG reviewed the findings of the advisory panels using an interactive Geographic Information System (GIS) tool (Killpack et al. 2000). The GIS tool included the information provided by the SAP as well as socioeconomic information about the major commercial and recreational activities in the Channel Islands. Technical facilitators assisted the MRWG with the tool at several public meetings (Killpack et al. 2000), which allowed the MRWG and members of the public to view and query the data, as well as to develop and evaluate designs for the marine reserves. If a particular design did not meet the ecological criteria, then the members of the MRWG adjusted the boundaries to satisfy conservation goals. Alternately, if a particular design had a high potential economic impact, members of the MRWG were able to adjust the boundary of the proposed reserve to limit the potential impacts.

Various designs for networks of marine reserves in the Channel Islands, developed by the MRWG, were given to the advisory panels for review. The SAP evaluated the designs based on the ecological criteria and provided suggestions for improvement to meet goals for biodiversity conservation and sustainable fisheries. The economic advisory panel conducted

economic impact analysis to determine the potential impacts to commercial and recreational activities. Using information from the advisory panels, the MRWG adjusted designs to meet the greatest number of goals. During the process, the MRWG developed and reviewed over 40 designs.

After evaluating a broad range of options, members of the MRWG were not able to reach consensus on a single design. However, in May 2001 the MRWG produced a map representing the two alternative designs and all of the information generated during deliberations of the MRWG and its advisory panels to the Sanctuary Advisory Council (SAC). The SAC reviewed and forwarded the information to the California Department of Fish and Game and the Sanctuary. In June 2001, the Department and the Sanctuary developed a compromise between the two maps, based on the information provided by the MRWG and its advisory panels.

After required analysis and public review, and the California Fish and Game Commission approved a final map, the network of state MPAs was established in April 2003. The network includes ten no take marine reserves and two conservation areas that allow limited commercial and recreational fishing (see Figure B).

The network of marine reserves includes many of the sites identified by the scientists, but the size of the network was smaller than the scientists had recommended. The SAP determined that the adopted network is likely to contribute to local conservation of biodiversity, but is unlikely to contribute substantial spillover or export to surrounding fisheries due to the small size of individual reserves. Thus, the adopted design is likely to achieve some, but not all of the goals established by the MRWG.

Challenges to MPAs in the Channel Islands

Controversy over marine reserves was intense during the planning stages and did not stop after the state MPA network was formally approved. For instance, while many recreational and commercial fishermen supported the reserves, and were even among the first to propose them, other fishermen opposed them. There was heated and often bitter public debate in meetings and in the written and electronic media. Some commercial fishermen objected to the MPAs because they felt that they might have unbearable short-term economic impacts. Recreational fishing groups felt that they were not the cause of the problem and so should not have to bear the burden of conservation.

Fishermen who objected to the reserves sought a temporary restraining order in Ventura County Superior Court to halt implementation. The group argued that the reserves would financially impact their businesses and that the California state agencies did not comply with existing regulations during the multi-year process to establish the reserves. The judge ruled that blocking the reserves was against the public's interest and that the plaintiffs were unlikely to prevail in court and so he refused to issue a temporary restraining order. On April 9, 2003 the state MPAs officially went into effect (Title 14, California Code of Regulations, Sections 27.82, 530, and 632).

Although challenging, the process of considering and then creating marine reserves as a management tool in the Channel Islands brought together science, economics, and public opinion to develop a solution to a complex management problem.

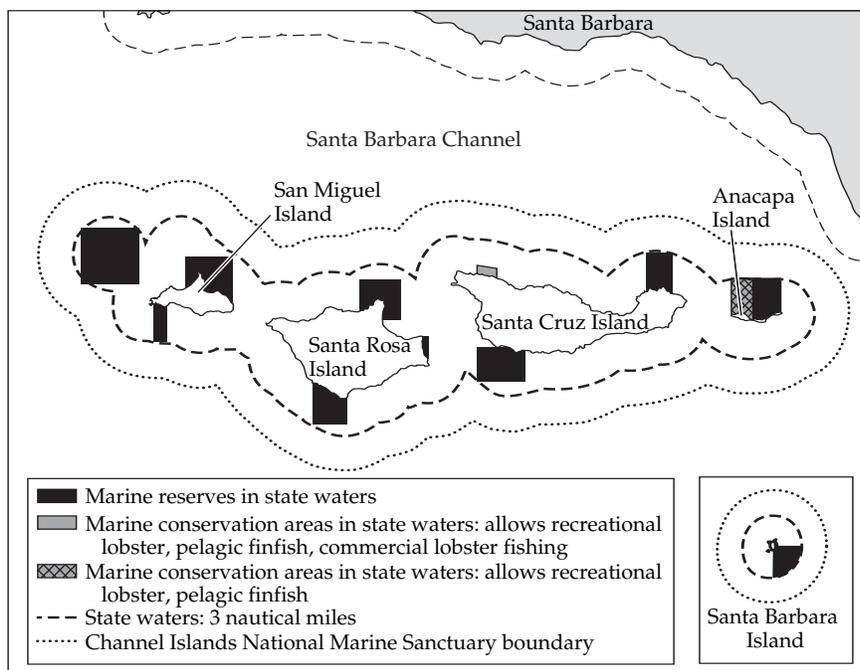


Figure B The Channel Islands network of marine protected areas. Santa Barbara Island is located about 40 km southeast of the other islands, so it is shown in the inset box. (Modified from the Channel Islands National Marine Sanctuary 2004.)

CASE STUDY 14.3

Reconciling Theory and Practice in Designing a Regional Reserve System

A Colombian Case Study

Gustavo Kattan, Wildlife Conservation Society, Colombia Program

A regional reserve system should be representative, resilient, redundant, and restorative. This so-called “four-R framework” (Groves 2003) sounds simple, but presents formidable challenges to a practitioner involved in conservation planning. In this case study, I present the perspective of a person standing between conservation science and practice, with the additional handicap of working in a scientifically developing country. How do we reconcile the rigor of science with the reality in the field?

The Implications of the Four-R Framework

Representative means that the system should represent the variety of biological manifestations in a region, from landscapes and communities to genes. However, seeking to attain this is not a practical objective, so The Nature Conservancy (1997) proposed an operational concept, the so-called coarse filter (ecosystems)—fine filter (species) approach. The coarse filter is an application of the umbrella principle. By conserving ecosystems (represented in areas large enough to be viable), we hope to conserve all their communities and ecological processes. However, focal species (species of special interest) may not be represented in these areas, so a special effort is made to ensure their inclusion in protected areas. Therefore, at the very least, achieving adequate representation requires knowing the distribution of native ecosystems and focal species in the region, with enough precision to be able to map them. In addition, applying the principle of representation requires setting quantitative goals: what proportion of original ecosystems do we want to preserve? In how many areas? Certainly the consequences of representing 10% of the extent of original ecosystems in one large, contiguous area or in ten small, disjunct areas differ in many ways.

The resilience of the reserves, which is a function of area, also needs to be considered. Larger reserves contain more complete sets of species and have a higher probability of maintaining their biological integrity over time.

The principle of redundancy is also relevant for deciding on number of areas. Redundant reserves—reserves that contain ecosystems and species that are already represented in the system—are an insurance policy against the possible catastrophic loss of some areas. Redundancy is particularly important for small reserves.

Finally, habitat restoration is a tool for achieving conservation goals when the area of an ecosystem needs to be increased or isolated reserves need to be connected.

The Need for Reserve System Planning in Colombia

Colombia is presently revising its national system of protected areas. The system has been in place for over 40 years, but there are gaps in ecosystem representation. For example, many parks and reserves in the Andean region were established to protect the headwaters of important river systems. Thus, parks are concentrated at the upper elevations, whereas lower slopes and inter-Andean valleys are unrepresented. This parallels the pattern of human occupation and landscape transformation, which in turn, was determined by the more benign climate, favorable topography and fertile soils of the mid-elevations. Unfortunately, these are also hot spots of biological diversity and endemism.

To facilitate the process of constructing the system of protected areas, the country was regionalized, and each region made responsible for designing its own system. This follows a political trend of decentralization, increased regional autonomy, and transfer of environmental responsibilities from the central government to regions and municipalities. Most regions are defined by jurisdictions of government agencies and socioeconomic and cultural factors, but little biology. Eventually, regional systems of protected areas will be integrated into a national system.

Developing a Reserve System in Eje Cafetero

One region currently constructing its regional system of protected areas is the “Eje Cafetero” or main coffee growing region of the country (hence “SIRAP-EC” for Sistema Regional de Areas Protegidas del Eje Cafetero). This is a region of about 30,000 km² encompassing the middle portion of the western and central ranges of the Andes and the Cauca Valley. Two features of this region present serious challenges for the planning process. First is a lack of biological knowledge. In spite of having several major urban centers with important academic institutions in or around the region, biological knowledge is insufficient for a rigorous planning process. Thus, we can refer to regional distributions of ecosystems and species only on a very general level. Second is the degree of landscape transforma-

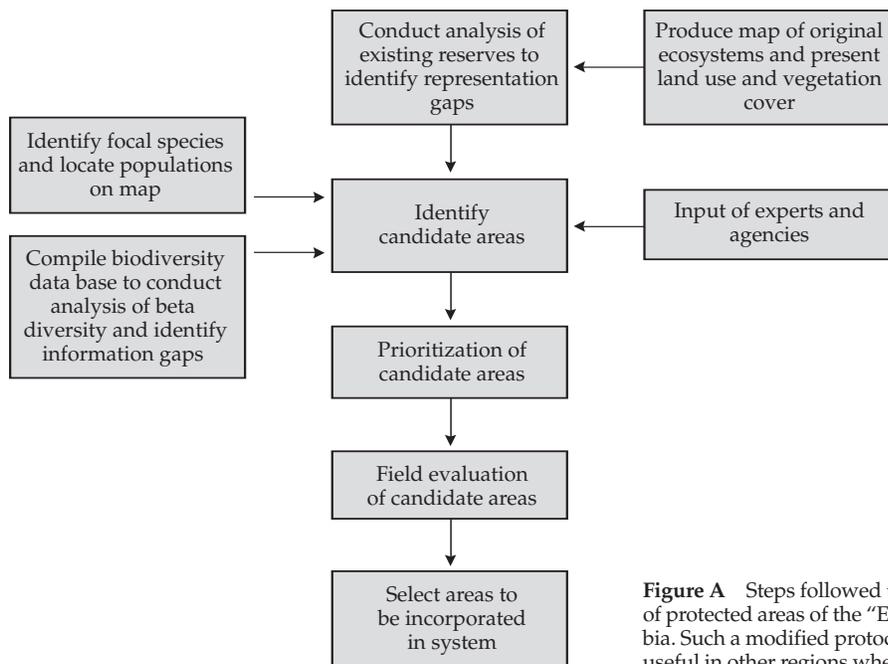


Figure A Steps followed to identify candidate areas for the regional system of protected areas of the “Eje Cafetero” or coffee growing region of Colombia. Such a modified protocol for systematic conservation planning may be useful in other regions where detailed data on biodiversity are lacking.

tion. As expected, for one of the most economically productive regions of the country (coffee is one of the pillars of Colombian economy), only a few small and isolated patches of natural ecosystems remain below 2000 m of elevation. These features are common to most of Andean Colombia, and probably other countries as well.

The planning process followed several steps (Groves et al. 2002; Figure A). We started by producing a map of original ecosystems and current land use and vegetation cover (from a variety of sources, including satellite images). Our first challenge was to define original ecosystems. Although the region was significantly transformed as recently as the first half of the twentieth century, there are no descriptions of original ecosystems and their distribution, much less of species distribution. Our only option was to use the Holdridge life-zone classification system, as a general guide to the variety of potential vegetation cover types in the region. For practical reasons, we simplified the system and divided the region into subregions and elevational zones (Kattan and Franco 2004; Kattan et al. 2004). This method probably ignores internal heterogeneity of subregions, but present knowledge does not permit a finer classification.

Using these maps, we conducted a gap analysis to evaluate the existing set of protected areas. For each subregion and elevational zone, we calculated the proportion of remnant natural vegetative cover, and the proportion currently included in protected areas (national, regional, municipal, and private reserves). Not surprisingly, we found that some ecosystems are unrepresented in the system, and that many protected areas are very small, which may reduce their long-term viability.

At the same time, we started constructing a regional biodiversity data base that has two components. The first is a data base of potential biota by subregions. This was only possible for groups such as birds and mammals, for which some general knowledge of geographic distribution was available (see Kattan et al. 2004). This information was used to conduct an analysis of potential beta diversity among subregions. The second data base is a compilation of all available locality records (in the published literature, reports, and museum specimens) of species in the region. In addition to compiling information on regional species distributions, this data base serves to identify geographic and taxonomic information gaps. This exercise revealed the second major challenge—the insufficiency of our biological knowledge of the region. At present the data base has about 30,000 species-locality records, or one per square km, which is dismally inadequate for such a biologically heterogeneous region. There is also great geographic and taxonomic bias in this knowledge. Some regions are totally unexplored, and most records that exist are for birds and plants. For example, there are on average nine records per bird species, but only one per insect species (for the few insects included). This means that for many species there is only one record for an entire region. This is hardly adequate for predicting species distributions and making sure that viable populations are properly protected.

A parallel line of work concentrated on focal species (fine filter approach). By expert consensus, two categories of focal species were made: at-risk species (i.e., under some degree of national or regional threat), and species that could be used as surrogates for conservation planning (in the sense of Lambeck

1997 and Sanderson et al. 2002). This region, however, is very rich in restricted-range species, most of which are at risk, and a first analysis produced an unmanageable number of focal species. We settled on selecting the vertebrate (fishes, frogs, birds, and mammals) and plant (timber trees) species with the highest priority as conservation targets (information was unavailable for invertebrates). Our objective was to make sure they were included in protected areas, which required information on distribution and population status, which of course we lack. One of the top priority species is the Cauca Guan (*Penelope perspicax*, Cracidae), a galliform, fruit-eating bird with a geographic distribution restricted to the middle Cauca Valley. This species has lost 95% of its habitat and is presently reduced to a few isolated populations (Renjifo 2002).

To proceed to the next step, (i.e., selecting candidate areas), we needed to set representation goals. The next major hurdle was to we define quantitative goals. Some options have been suggested (Groves 2003) including: (1) species-area relationships; (2) beta diversity; (3) minimum dynamic area (Pickett and Thompson 1978). The species–area relationship dictates that 30%–40% of the area of a given ecosystem is required to preserve 80%–90% of species. The question then becomes: Do we create one reserve or several reserves adding up to this percentage? Beta diversity may be of help, as it dictates the number and location of areas necessary to represent regional species diversity. We know that each of our subregions represents different ecosystem types and species assemblages; thus, we need reserves in each subregion. We also know that there is significant beta diversity within subregions. A study of bird diversity on the western slope of the Central Cordillera revealed high beta diversity among elevational belts and among river drainages (Kattan et al. unpublished data; this study also revealed that fragmentation increases beta diversity because of differential extinction of local populations). We have no information on minimum dynamic area (patch dynamics), except that we know the larger, the better. We then decided to aim for 30%–40%, trying to distribute areas over entire subregions (covering entire altitudinal gradients whenever possible), and to make each area as large as possible.

The reality, of course, is that in our region there are not enough remnants to represent 30%–40% of original ecosystems, at least in some subregions. Some ecosystems, such as dry forest and wetlands on the valley floor, and pre-montane forest fragments in the coffee-growing elevational belt (1000 m to 1800 m), are in a critical state, with only a few small and isolated fragments remaining. So we revised our plan, and aimed to preserve 100% of remnants of critical ecosystems while identifying restoration opportunities to increase their cover.

Is it worth it to invest in the preservation of small, probably degraded fragments? The answer is a categorical yes. It is clear that many species have been lost. Two studies, based on his-

torical data, demonstrated that forest fragmentation caused local extinction of about 30% of bird species (Kattan et al. 1994; Renjifo 1999). Habitat fragments, however, are still important repositories of the regional biodiversity, including populations of endemic and endangered species (Kattan and Alvarez-López 1996). Are these fragments going to lose integrity over time? Possibly, but pre-montane forests may be more resilient than commonly believed. This has to do with the inherent patch dynamics and high population densities of some animals and plants in these forests (Murcia and Kattan, unpublished data).

The next step is selecting candidate areas to be included in the system. A variety of criteria and tools are available to assist the selection process (e.g., reserve-selection software; Groves 2003). Our situation was simple, however, as our options were limited to a few available areas. These areas were delimited on a map in an experts' workshop, following a simple algorithm: select all the areas you believe have any possibility of being protected, aiming to satisfy criteria of representation, beta diversity, redundancy, and large size (we called this our digital system of reserve selection, as experts pointed their fingers at areas in the map). Still, areas had to be prioritized, for which we used the irreplaceability and vulnerability concepts as described in this chapter (Groves 2003). Areas were ranked by experts according to these two variables taking into account predefined criteria, and the highest priority was assigned to areas scoring in the top 50% for both variables. The second priority was given to areas with high irreplaceability and low vulnerability, third priority to areas with high vulnerability and low irreplaceability, and the lowest priority to areas scoring low on both variables. We are still working to refine our proposed reserve system to allow viable populations of focal species to persist.

We approached the design of the SIRAP-EC with a scientific frame of mind, but faced two major limitations: lack of sufficient biological knowledge for a rigorous design, and a highly fragmented region, which severely limited design options. Under these circumstances, our version of the four-R framework (coarse filter approach) can be summed up in the following words: complement, expand and connect areas as much as possible. That is, (1) include complementary areas to represent all regional ecosystems and beta diversity, even if it means representing a small percentage of the original ecosystems; (2) identify opportunities to expand protected areas, either by adding habitat blocks where available, or by restoring habitat; and (3) connect habitat fragments as much as possible, either by habitat restoration or by identifying productive matrices that foster connectivity (Durán and Kattan 2005). And our version of a fine filter approach is to try to include all known populations of at-risk species in protected areas.

Summary

1. Setting aside protected areas are one of the most effective tools available for conserving biodiversity and can also provide other benefits such as protecting water supplies and cultural values, and sustaining the livelihoods of indigenous groups. Protected areas range from those that are strictly protected, and in which extractive uses are excluded, to multiple-use areas in which the sustainable extraction of natural resources is allowed. While the coverage of protected areas has more than doubled in the past decade, analyses of reserve systems at global, regional, or national scales indicate that there are gaps and biases in the representation of biodiversity. Creating a global, ecologically representative reserve system that is well-managed will require substantial financial investment. Thus, there is a need to prioritize the allocation of scarce conservation resources to the expansion of existing protected areas so that returns for biodiversity conservation are maximized.
2. Recent research efforts in the field of conservation planning have focused on the development of principles and tools to design efficient reserve systems that represent as much biodiversity as possible at a fixed cost. Systematic conservation planning has informed reserve system design in both terrestrial and marine realms. For example, conservation planning principles and tools informed the conservation plan recently developed for the Cape Floristic Region of South Africa and were the basis of the recent rezoning of the world's largest marine park—the Great Barrier Reef Marine Park of Australia.
3. This chapter focuses on the functions, design, and limitations of protected areas and the processes of conservation planning. By considering all the complexities of conservation planning, we can see that

the science of reserve system planning is still in its infancy. How to address the limitations of data and incorporate ecological, social and political processes are active areas of research.

Please refer to the website www.sinauer.com/groom for Suggested Readings, Web links, additional questions, and supplementary resources.

Questions for Discussion

1. What is the irreplaceability of a protected area? Explain your answer using an example of both a completely replaceable and completely irreplaceable protected area. What is adequacy in the context of conservation planning for reserve systems and how could we measure and plan for adequate reserve systems?
2. Are all protected areas managed in the same way? Discuss the IUCN protected area management categories and provide explanations and illustrations of each category.
3. Why wouldn't we add any area we can cheaply acquire to an existing reserve system as fast as possible?
4. In what way does the phrase "the whole is more than the sum of the parts" apply to a systematically designed reserve system?
5. If we conserved 15% of every biome in the world would that be enough to ensure the long-term persistence of global biodiversity?