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Lessons in Conservation (LinC)
Developing the capacity to sustain the earth's diversity

Dear Reader,

We welcome you to the first issue of LinC, Lessons in Conservation, the official journal of the Network of Conservation Educators and Practitioners (NCEP, http://ncep.amnh.org) of the Center for Biodiversity and Conservation (CBC) of the American Museum of Natural History. On these pages, you will find selected NCEP teaching modules, presented in an easy-to-browse PDF format. LinC is designed to introduce NCEP teaching materials to a broad audience. After browsing through LinC, we hope that university faculty members and other teachers and trainers will be inspired to visit and download additional materials from the NCEP site, and to try them in the classroom. We welcome feedback on our modules and we especially welcome those wishing to become further involved in the project!

Topics in this first issue of LinC range from marine conservation biology to ecosystem loss and fragmentation to assessing threats, and include both Synthesis summary documents and Exercises for classroom or field use. Future issues will be released semi-annually, and will include Case Studies to complement our Syntheses and Exercises. Future issues will also include brief reports from teachers and trainers using and testing the modules.

Many people from the CBC and the NCEP network of collaborators have contributed to the development of LinC over the past year. On our back cover, we are pleased to acknowledge the foundations and individuals that have supported this project. Special thanks go to Dr. Kathryn Hearst for providing the funding needed to bring this inaugural issue to completion.

We look forward to your input and comments, and to seeing you again soon on these pages!

Eleanor Sterling — Co-Editor

Nora Bynum — Co-Editor

NCEP Workshops and activities in (from left to right) Rwanda, Bolivia, and California.

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Introduction to Marine Conservation Biology

Tundi Agardy

This document is specifically about those aspects of marine biology that are used in marine conservation. It is not intended to be a complete primer on marine conservation, which incorporates other sciences (most notably the social sciences) as well as traditional knowledge. To learn more about other aspects of marine conservation, please refer to the following marine modules: *Marine Conservation Policy, Marine Protected Areas and MPA Networks*, and *International Treaties for Marine Conservation and Management*, all of which complement this module.

Introduction

Marine and Coastal Systems

Almost three-quarters of the Earth's surface (exactly 70.8% of the total surface area or 362 million km^2), is covered by oceans and major seas. Within these marine areas are ecosystems that are fundamental to life on earth and are among the world's most productive, yet threatened, natural systems. *Continental shelves* and associated Large Marine Ecosystems (LMEs) provide many key ecosystem services: shelves account for at least 25% of global primary productivity, 90-95% of the world's marine fish catch, 80% of global carbonate production, 50% of global denitrification, and 90% of global sedimentary mineralization (UNEP, 1992).

Marine systems are highly dynamic and tightly connected through a network of surface and deep currents. In marine systems, the properties of the watery medium generate density layers, *thermoclines*, and gradients of light penetration. These phenomena give the systems vertical structure, which results in vertically variable productivity. Tides, currents, and *upwellings* break this *stratification* and, by forcing the mixing of water layers, enhance production (MA, 2005c). Coastal systems also exhibit a wide variety of habitats that in turn contribute significantly to global biological diversity.

Marine and coastal systems play significant roles in the ecological processes that support life on earth and contribute to human well-being. These include climate regulation, the freshwater cycle, food provisioning, biodiversity maintenance, and energy and cultural services including recreation and tourism. They are also an important source of economic growth. Capture fisheries alone were worth approximately 81 billion USD in 2000 (FAO, 2002), while aquaculture netted 57 billion USD in 2000 (FAO, 2002). In 1995, offshore gas and oil was worth 132 billion USD, while marine tourism brought in 161 billion USD, and trade and shipping were worth 155 billion USD (McGinn, 1999). There are currently approximately 15 million fishers employed aboard fishing vessels in the marine capture fisheries sector, the vast majority on small boats (90% of fishers work on vessels less than 24 m in length) (MA, 2005c).

Key Concepts in Marine Conservation Biology

Marine ecosystems are complex and exhibit diversity at various hierarchical levels. Of 32 common phyla on the earth, only one living phylum is strictly terrestrial; all others have marine representatives (Norse, 1993). Interestingly, all of these phyla had differentiated by the dawn of the Cambrian, almost 600 million years ago, and all evolved in the sea. Since that time the sea has been frozen, experienced extensive anaerobic conditions, been blasted by meteorites, and undergone substantial sea level variation. The sea has thus been fragmented and *coalesced*, resulting in a vast array of habitats (MA, 2005a).

Marine species are poorly known relative to those on land. The actual species diversity in the ocean is not known, and fewer than 300,000 of the estimated 10 million species have been described (MA, 2005a). One of the rare efforts to sample all of the *mollusk* species at a tropical site found 2,738 species of marine mollusks in a limited area near New Caledonia (Bouchet et al., 2002).

Natural systems in the sea, as on land, exhibit non-linear dynamics. Thresholds for responses to perturbation occur in some systems, though few have actually been identified. Significant alteration in ecosystem structure and function can occur when certain triggers result in changes in the dominant species. *Regime shifts* are common in *pelagic* fisheries, where thresholds are surmised to be related to temperatures (IPCC, 2003). Most well known is the example of the anchovy/sardine regime shift, which is expressed as a periodic oscillation between dominant species, not an irreversible change. Irreversible shifts occur when a system fails to return to its former state in time scales of multiple human generations, after driving forces leading to change are reduced or removed (IPCC, 2003).

Pillar coral, *Dendrogyra cylindrus*, and juvenile bluehead wrasse off of the coast of Andros Island (Source: D. Brumbaugh)

Some phase shifts are essentially irreversible, such as the coral reef ecosystems that undergo rather sudden shifts from coral-dominated to algal-dominated reefs (Birkeland, 2004). The trigger for such changes is usually multi-faceted, and includes increased nutrient input. This leads to eutrophied conditions and removal of the herbivorous fishes that maintain the balance between corals and algae. Once the thresholds for the two ecological processes of nutrient loading and herbivory (one upper and one lower) are passed, the phase shift occurs suddenly (within months). The resulting ecosystem, though stable, is less productive and less diverse. Human well being is affected not only by reductions in food supply and decreased income from reef-related industries (e.g., diving and snorkeling, aquarium fish collecting, etc.), but also by increased costs accruing from the decreased ability of reefs to protect shorelines. Algal reefs, for example, are more prone to being broken up in storm events, leading to shoreline erosion and seawater breaches of land. Such phase shifts have been documented in Jamaica, elsewhere in the Caribbean, and in Indo-Pacific reefs (MA, 2005b).

Introduced alien species (or invasive species) can also act as a trigger for dramatic changes in ecosystem structure, function, and delivery of services. In the marine environment, species are commonly brought into new areas through *ballast water* discharges, and can quickly gain a foothold as they outcompete native species for food and space. A prime example of a sudden, and irreversible, change in an ecosystem occurred in the Black Sea. Introduction of the carnivorous *ctenophore Mnemiopsis leidyi* caused the loss of 26 major fisheries species, and has been implicated (along with other factors) in subsequent growth of the *anoxic* "dead zone" (Zaitsev and Mamaev, 1997). Introduced species arrive via other vectors as well, such as through the disposal of packing materials for marine resources, and are not always accidental.

Changes in biodiversity and other environmental changes influence each other, in marine systems as well as in terrestrial. Biodiversity loss can reduce an ecosystem's resilience to environmental perturbation. This can be brought about by, for example, climate change (warming), ozone depletion (increased radiation), and pollution (*eutrophication*, toxics). All of these impacts can also reduce biodiversity. Diverse marine systems in which neither species, population, nor genetic diversity has been severely constricted, are better able to adapt to changing environmental conditions (Norse, 1993). Unaltered coral reefs, for instance, are less likely to experience disease-related mortality when ocean temperatures increase (Birkeland, 2004). However, all environmental change has the potential to cause biodiversity loss, especially at the level of genes and populations. The greater the magnitude and the more rapid the rate of change, the more likely biodiversity will be affected, and the greater the probability that subsequent environmental change will lead to greater ecosystem degradation (MA, 2005a).

Comparisons Between Marine and Terrestrial Systems

Marine and terrestrial systems exhibit differences in scale and process (Steele, 1985). The obvious distinction is that on land, air is the primary medium for food transmission, and in marine systems, water is the primary medium. Although both terrestrial and marine systems exist in three-dimensional space, land-based ecosystems are predominantly two-dimensional, with most ecological communities "rooted" to the earth's surface. The seas present a different picture, with the bulk of life moving about in a non-homogeneous space, and few processes linking the water column with the *benthos*. The water medium has freed organisms from the constraints on body type posed by gravity, thus the array of life, as expressed by *phyletic diversity*, is much wider in the sea (Kenchington and Agardy, 1990; Norse, 1993). In the sea and its coastal interface, the transport of nutrients occurs over vast distances, and both passive movement and active migrations contribute to its highly dynamic nature. Marine species must also meet the challenges posed to reproduction in an aqueous environment: gametes released into the water column are quickly dispersed, and most species are highly *fecund* and time their *spawning* to release gametes en masse (Kenchington and Agardy, 1990). Perhaps most importantly, physical features of the marine ecosystem dictate its character, more so than on land (Agardy, 1999).

In the marine environment, all habitats are ultimately connected – and water is the great connector. Some habitats are more intimately and crucially linked, however. Coral reefs provide a good example of this interconnectedness. For years, diverse and biologically rich coral reefs were thought of as self-contained entities: very productive ecosystems with nutrients essentially locked up in the complex biological community of the reef itself. However, many of the most crucial nursery habitats for reef organisms are actually not on the coral reef itself, but rather in seagrass beds, *mangrove forests*, and sea mounts sometimes far removed from the reef (Hatcher et al., 1989). Currents and the mobile organisms themselves provide the linkages among the reefs, nursery habitats, and places where organisms move to feed or breed (Mann and Lazier, 1991; Dayton et al., 1995). Thus, managing marine systems like coral reefs requires addressing threats to these essential linked habitats as well.

The ocean and coastal habitats are not only connected to each other, they are also inextricably linked to land (Agardy, 1999). Although the terrestrial systems are also linked to the sea, this converse relationship is neither as strong nor as influential as is the sea to land link. Freshwater is the great mediator here. Rivers and streams bring nutrients as well as pollutants to the ocean, and the ocean gives some of these materials back to land via the atmosphere, tides, and *seiches*. Other pathways include the deposition of *anadromous* fish (Deegan, 1993). Many coastal habitats, such as estuaries, are tied closely to land, and are greatly affected by land use and terrestrial habitat alteration (MA, 2005b).

In coastal and marine systems, habitats include freshwater and brackish water wetlands, mangrove forests, estuaries, *marshes*, *lagoons* and salt ponds, rocky or muddy *intertidal* areas, beaches and dunes, coral reef systems, seagrass meadows, kelp forests, nearshore islands, semi-enclosed seas, and nearshore coastal waters of the continental shelves. Many of these coastal systems are highly productive and rival the productivity of even the most productive terrestrial systems (MA, 2005b). Table 1 illustrates the relative productivity of some of these coastal ecosystems in comparison to select terrestrial ecosystems.

Table 1: Relative productivity estimates for select coastal and terrestrial ecosystems

Ecosystem type	Mean net primary productivity (g.m.$^{-2}$ year^{-1})	Mean biomass per unit area (kg/m^2)
Swamp and march	2000	15
Continental shelf	360	0.01
Coral reefs and kelp	2500	2
Estuaries	1500	1
Tropical rain forest	2200	45

Source: Modified from Table 3-4 in Odum and Barnett, 2004

Marine Organisms and Environments

Marine Biodiversity

Habitat diversity

Biodiversity is defined as the variety of life in all of its forms. Although we usually think of diversity in terms of species numbers, an equally important metric is the amount of variability of habitat within a unit area, or the spatial autocorrelation of species within an area (MA, 2005a). This is broadly known as beta-diversity (see the *What is Biodiversity* module). The oceans and coastal areas exhibit a vast array of habitat types, and many ecosystems are highly diverse at this level of organization.

Phyletic and species diversity

Phyletic diversity in the sea is much greater than on land. Major marine phyla include microbes, such as *protists*, fungi, bacteria, archaea; plants such as algae and flowering plants like sea grasses; invertebrates such as *sponges*, *cnidarians*, *echinoderms*, mollusks, *crustaceans*; and vertebrates, including the bony and cartilaginous fishes, reptiles (sea turtles, sea snakes, marine iguanas), mammals (sea otters, manatees and dugongs, seals, whales and dolphins) and birds (seabirds, shorebirds, etc.).

Species richness is valued as the common currency of the diversity of life - the "face" of biodiversity. The problem with this emphasis is the potential masking of important trends and properties, beyond taxonomy (MA, 2005a). Given the complexity of biodiversity, species- or other taxon-based measures-rarely reflect the real attributes that provide insight into roles and functions. There are several limitations associated with the emphasis on species. First, what constitutes a species is often not well defined (MA, 2005a). For example, it is not necessarily easy to know when one is measuring population or species diversity. Indeed, the dynamic nature of marine systems confounds the species/population dichotomy, since members of the same marine species are often isolated by populations so discrete that intermixing is functionally impossible (see discussion of genetic diversity, below).

Second, species richness and ecosystem function may not correlate well. Productive ecosystems, such as estuaries or wetlands, are often species poor. Third, although species are taxonomically equivalent, they are rarely ecologically equivalent. For example, taxa that are *ecosystem engineers*, like beavers or marine worms, and *keystone species*, whose presence maintains a diverse array of species in a community, often make greater contributions to ecosystem functions than others. Fourth, species vary extraordinarily in abundance, often exhibiting a pattern in which only a few are dominant, while many are rare (MA, 2005a). Thus, to simply count taxa does not take into consideration how variable each might be in its contribution to ecosystem properties.

Genetic diversity

The fundamental differences in marine and terrestrial ecosystems are in degree, not in kind (Steele, 1995). But there are semantic problems that arise from the different ways we label marine systems and those on land. Understanding species diversity and genetic diversity in the sea is a case in point. Most marine species are widespread in distribution, being cosmopolitan or even circumglobal. However, marine populations are structured into distinct demes, such that the genetic make-up of a population or stock can be profoundly different from that of a neighboring stock or population, even though we refer to them as being of the same species.

Physical Oceanography

Physical Environment at Various Scales

The physical environment of the oceans drives their biological make-up to a greater degree than in terrestrial systems. The oceanographic phenomena that underlie how the oceans are structured and how they function occur at three scales. The first is the macro-scale, on which large-scale hydrographic processes and patterns manifest themselves in oceanographic circulation and major currents. On the *meso-scale*, temperature and salinity create *thermohaline* regimes. On the micro-scale, tidal exchange, upwelling, and *longshore currents* frame the physical environment of different marine habitats in different coastal and continental shelf areas.

Macro scale oceanography

Although the ocean waters appear homogeneous, there are both stratification into horizontal layers and vertical mixing between layers that take place below the visible surface. The surface layer, with uniform hydrographic properties, is an essential element of heat and freshwater transfer between the atmosphere and the ocean. It usually occupies the uppermost 50 - 150 m, but can reach much deeper. Winter cooling at the sea surface produces convective overturning of water, releasing heat stored in the ocean to the atmosphere. During spring and summer, the mixed layer absorbs heat, moderating the earth's seasonal temperature extremes by storing heat until the following autumn and winter. Mixing is achieved by the action of wind waves, which cannot reach much deeper than a few tens of meters, and tidal action. Below the layer of active mixing is a zone of rapid transition, where (in most situations) temperature decreases rapidly with depth. This transition layer, called the seasonal thermocline, is shallow in spring and summer, deep in autumn, and disappears in winter. In the tropics, winter cooling is not strong enough to destroy the seasonal thermocline, and a shallow feature, sometimes called the tropical thermocline, is maintained throughout the year (Tomczak, 2000).

The depth range from below the seasonal thermocline to about 1000 m is known as the permanent or oceanic thermocline. It is the transition zone from the warm waters of the surface layer to the cold waters of great oceanic depth. The temperature at the upper limit of the permanent thermocline depends on latitude, reaching from well above 20°C in the tropics to just above 15°C in temperate regions. At the lower limit, temperatures are rather uniform around 4 - 6°C, depending on the particular ocean (Tomczak, 2000).

Meso scale oceanography

Ocean and atmosphere form a coupled system. The coupling occurs through exchange processes at the sea surface interface (Tomczak, 2000). These determine the energy and mass budgets of the ocean. In the North Atlantic, for example, solar heating and excess evaporation over precipitation and runoff creates an upper layer of relatively warm, saline water in the tropics. Some of this water flows north, through the passages between Iceland and Britain. On the way it gives up heat to the atmosphere, particularly in winter. Since winds at these latitudes are generally from the west, the heat is carried over Europe, producing the mild winters that are so characteristic of that region, relative to others at similar latitudes. So much heat is withdrawn that the surface temperature drops close to the freezing point. This water, now in the Greenland Sea, remains relatively saline, and the combination of low temperature and high salinity makes the water denser than deeper water below it. Convection sets in and the water sinks - occasionally and locally right to the bottom. There it slides under and mixes with other water already close to the bottom, spreading out and flowing southward, deep. This thermohaline circulation (warm surface water flowing north, cooling, sinking and then flowing south) provides an enormous northward heat flux (Stewart, 1991).

Circulation at the surface of the oceans is wind-driven. It is generally referred to as zonal or meridian flow, depending on whether it is predominantly across latitudes or longitudes (IPCC, 2003). Under about 1 kilometer of depth, however, water flows are not driven by wind but rather by temperature (thermal) and salinity (haline) effects. This is known collectively as thermohaline circulation. The driving force for thermohaline circulation is water mass formation. Water masses with well-defined temperature and salinity are created by surface processes in specific locations. They then sink and mix slowly with other water masses as they move along. The two main processes of water mass formation are deep convection and subduction, which are linked to the dynamics of the mixed layer at the surface of the ocean (Tomczak, 2000).

The thermohaline circulation described above has become known as the 'Great Ocean Conveyor Belt' (Tomczak, 2000). The water that sinks in the North Atlantic Ocean (North Atlantic Deep Water) enters the Antarctic Circumpolar Current and from there, all ocean basins, where it rises slowly into the upper kilometer and returns to the North Atlantic in the permanent thermocline. Although this is only one of the circulation paths of North Atlantic Deep Water, it is the most important from the point of ocean/atmosphere coupling, since it acts as a major sink for atmospheric greenhouse gases. The only other region of similar importance is the Southern Ocean, where Antarctic Bottom Water sinks.

Micro scale oceanography

Tides, longshore currents, and upwellings also affect the ecology of marine areas. Tides are long waves caused by the force of gravity from the moon. The dominant period of tidal cycles usually is 12 hours 25 minutes, which is half a lunar day (Tomczak, 2000). Tides are generated by the gravitational potential of the moon and the sun, and their propagation and amplitude are influenced by friction, the rotation of the earth, known as *Coriolis force*, and resonances determined by the shapes and depths of the ocean basins and marginal seas. The most obvious expression of tides is the rise and fall in sea level. Equally important is a regular change in current speed and direction; tidal currents are among the strongest in the ocean. If the tidal forcing is in resonance with a seiche period for the sea or bay, the tidal range is amplified and can be enormous, such as occurs in the Bay of Fundy on the Canadian east coast, which with 14 meter tides has the largest tidal range in the world (Tomczak, 2000).

Longshore currents result from coastal topography, and are highly influenced by coastal constructions such as breakwaters, jetties, seawalls, etc. Perhaps even more than tidal regimes, longshore currents influence the distribution and abundance of coastal marine organisms. Even offshore marine biodiversity is affected by longshore currents, since some pelagic species have some life stages in nearshore waters (MA, 2005b).

Upwellings are vertical currents that deliver cold, nutrient-rich bottom waters to the surface (Tomczak, 2000). The most productive areas of the ocean are upwellings, including the Benguela upwelling off southwest Africa, and the Humboldt upwelling off Peru. These major upwellings are the product of the movement of cold bottom water hitting the edge of the continents and flowing upwards as a result; however, there are many minor upwellings that occur in places where the bottom topography influences deepwater currents. Upwelling areas may not be particularly diverse in species per unit area, but they support geographically massive food webs that include many marine organisms and seabirds. The extent to which upwellings provide a foundation for extensive food webs is highlighted by what happens during El Nino Southern Oscillation events in which upwelling flows diminish and large numbers of organisms, especially seabirds, starve.

Links Between Physical Oceanography and Biota

There is a strong correspondence between physical features in the ocean environment and biodiversity, irregardless of whether those features have to do with bottom topography or ocean circulation. In general, the more complex and heterogeneous the physical environment, the more productive and diverse are the food webs supported by it. Marine food webs are based largely on primary production by microscopic algae, the *phytoplankton*. This occurs in the lighted, upper layers of the ocean, especially the *coastal zone*. Production is intensified by processes that lift nutrient-laden water from deeper layers. Most of this production is then either grazed by herbivorous *zooplankton* (mainly *copepods*), or falls to the sea bottom in the form of detritus aggregates known as *marine snow*. It is attacked by bacteria on the way down, and consumed by benthic organisms upon reaching the sea bottom. Little marine snow reaches the bottom of tropical seas due to, among other things, the higher metabolic rates of bacteria in warm waters. Hence, there is less benthos, and fewer ground fish to catch in the deeper reaches of tropical seas, than in otherwise comparable temperate or polar seas. This creates a limit for the expansion of deep-sea bottom fisheries in tropical areas (MA, 2005c).

The higher the trophic level, the lower the biological production. In other words, the farther organisms are from phytoplankton and other primary producers, the smaller the population size and biomass. In fishes, the greatest production occurs at a trophic level of 3 (small fishes such as sardines and herrings that feed on herbivorous zooplankton), and near trophic level 4 (fish such as cods and tunas that prey on zooplanktivorous fishes). Many fish, however, have intermediate trophic levels, as they tend to feed on a wide range of food items, often feeding on zooplankton as juveniles and feeding on other fish as adults (Pauly et al., 1998). Biomass energy is transferred up the food web with transfer efficiencies between trophic levels ranging in marine ecosystems from about 5% to 20%, with 10% a widely accepted mean (MA, 2005c). This implies that the productivity of large, higher trophic level fish that have traditionally been targeted in the most lucrative fisheries is lower than that of less desirable, lower trophic level fishes. However, historical fishing has followed a path now known as "fishing down the food web" (Pauly et al., 1998), in which the natural proportion of predators and producers has been grossly altered, skewed towards the lowest trophic levels. This process is occurring as a result of the susceptibility to fishing pressure of large, slow-growing high trophic level fishes, which are gradually being replaced, in global landings, by smaller, shorter-lived fishes at lower trophic levels. Globally, both the landings and their mean trophic levels are currently going down under the pressure of fisheries (MA, 2005c).

Major Marine Ecosystems

Nearshore Ecosystems

Kelp forests and hard bottoms

Kelp forests are distinctive for the structure provided by the very large, anchored macroalgae that give this temperate habitat type its name; they occur in many different canopy types. The productivity of kelp ecosystems rivals that of the most productive land systems, and they are remarkably resilient to natural disturbances. They are highly diverse systems organized around large brown algae, and the complex biological structure supports a high variety of species and interactions (Dayton, 2003). They support fisheries of various invertebrates and finfish, and the kelps themselves are harvested. Kelp communities have many herbivores, but the most important are sea urchins, capable of consuming nearly all fleshy algae in most kelp systems. Unfortunately, predators which help keep urchins in check within kelp forests have been destabilized by fishing to such an extent that the kelp forests retain only a fraction of their former diversity (Dayton et al., 1998; Tegner and Dayton, 2000).

The temperate kelp forest is one of the best-understood marine communities in the world in terms of local processes at work at a particular time and location (Dayton, 2003). It is a system dominated by patch dynamics based on frequent disturbance, effective dispersal, and both inhibitory and facultative succession. Strong and weak interactions are well studied at the small scales (Paine, 2002). However, discerning the differences between direct human impacts from natural changes or changes related to regional or global change has proven difficult.

The paradigm of fishing impacts on coastal habitats cascading down to much simplified sea urchin-dominated barren grounds has proven very general (Sala et al., 1998; Steneck, 1998). The actual mechanisms, however, vary across systems. No kelp forest is pristine, and humans have vastly reduced expectations of how the systems should exist. For example, in the Atlantic large fish such as halibut, wolfish, and cod are the key predators of sea urchins. These predators largely have been removed from the system, and, as a result, sea urchin populations have exploded (Witman and Sebens, 1992; Steneck, 1998). Then, directed exploitation and disease have led to a collapse of the urchin populations leaving a once healthy and productive ecosystem degraded by waves of exotic species (Harris and Tyrell, 2001).

Non-kelp forested hard bottom communities are also highly productive, and important for fisheries. Below the *photic zone* these tend to be dominated by sponges, corals, bryozoans, and compound ascidia (Dayton, 2003). The architectural complexity provided by these colonies of organisms is important to supporting other living beings. They provide refuge from predators, and generally play an important role in maintaining the biodiversity and biocomplexity of the seafloor (Levin et al., 2001). In the more stable habitats, the species present are usually clones and long-lived individuals, and the associations are stable over decades and perhaps centuries. The populations are marked by very low dispersal, often with larvae that crawl only centimeters during their larval lifespan, and they are characterized by extreme resistance to competition, invasion, or predation (reviewed in Dayton, 1994).

Encrusting communities often appear to have several examples of alternative stable states that are self-perpetuating in the face of normal disturbances (Sebens, 1986). The mechanisms involve powerful, often chemical, defenses from predation and *biofouling*, asexual reproduction or non-dispersing larvae, and the ability to protect juveniles from predation (Dayton, 2003). Witman and Sebens (1992) demonstrated that overfishing along the coastal zone greatly reduced the top predators and caused population explosions in their prey. This in turn has changed much of the community structure. Aronson (1991) argues that this overfishing has virtually eliminated many evolutionarily "new" predators and released a "rebirth" of the Mesozoic communities dominated by echinoderms.

While robust to natural disturbances from predation, competition, and biofouling, the fact that the species in these systems tend to have extremely limited larval dispersal means the recolonization and recovery following perturbation can be very slow (Dayton, 2003). Lissner et al. (1991) consider many types of disturbances and the subsequent succession and recovery to the original association. Large disturbances, such as widespread damage from fishing gear, almost never allow recovery to the pre-existing condition (Dayton, 2003).

Estuaries and tidal wetlands such as mangroves

Estuaries—areas where the freshwater of rivers meets the saltwater of the oceans—are highly productive, dynamic, ecologically critical to other marine systems, and valuable to people. Worldwide, some 1200 major estuaries have been identified and mapped, yielding a total digitized area of approximately 500,000 square kilometers (MA, 2005b). Estuaries and associated marshes and lagoons play a key role in maintaining hydrological balance, filtering water of pollutants, and providing habitat for birds, fish, mollusks, crustaceans, and other kinds of ecologically and commercially important organisms (Beck et al., 2001; Levin et al., 2001). The 1200 largest estuaries, including lagoons and *fiords*, account for approximately 80% of the world's freshwater discharge (Alder, 2003; Figure 1 shows the largest of the world's estuaries). Of all coastal subtypes, estuaries and marshes support the widest range of services, and may be the most important areas for ecosystems services. One of the key processes is the mixing of nutrients from upstream as well as from tidal sources, making estuaries one of the most fertile coastal environments (Simenstad et al., 2000). There are many more estuarine-dependent than resident species, and estuaries provide a range of habitats to sustain diverse flora and fauna (Dayton, 2003). Estuaries are particularly important as nursery areas for fisheries and other species, and form one of the strongest linkages between coastal, marine, and freshwater systems and the ecosystem services they provide (Beck et al., 2001).

Estuaries and coastal wetlands are critical transition zones linking the land and sea (see review by Levin et al., 2001). Important nutrient cycling and fluxes, primary and secondary productivity, nursery areas, and critical habitats of many birds and mammals are examples of essential services provided by this once ubiquitous habitat. Most of these functions are mediated via sediment-associated *biota* including macrophytes (mangroves, salt marsh plants, and sea grass beds as well as macro algae), heterotrophic bacteria and fungi, and many invertebrate taxa. Functional groups (organisms with similar roles) include roles such as decomposition and nutrient recycling, resuspension, filter feeding, and bioturbation.

Plants regulate many aspects of the nutrient, particle, and organism dynamics both below and above ground. Further, they often provide critical habitats for endangered vertebrates. Importantly, a wide variety of animals move in and out of this habitat for many reasons, including the completion of life cycles, feeding, use of larval nurseries, and migration. The bioturbation (or movement of sediment by burrowers) is itself an important structuring mechanism, providing mounds and depressions that serve as habitats to hundreds of small invertebrate species (Dayton, 2003).

Mangroves are trees and shrubs found in intertidal zones and estuarine margins that have adapted to living in saline water, either continually or during high tides (Duke, 1992). Mangrove forests are found in both tropical and subtropical areas, and global mangrove forest cover currently is estimated between 16 and 18 million hectares (Spalding et al., 1997; Valiela et al., 2001). The majority of mangroves are found in Asia. Mangroves grow under a wide amplitude of salinities, from almost freshwater to 2.5 times seawater strength. They may be classified into three major zones (Ewel et al., 1998) based on dominant physical processes and geomorphological characters: a) tide-dominated fringing mangroves, b) river-dominated riverine mangroves, and c) interior basin mangroves. The importance and quality of the goods and services provided by mangroves varies among these zones in terms of habitat for animals, organic matter export function, reducing soil erosion, protection from typhoons, etc. (Ewel et al., 1998).

Soft sediments and sea mounts

About 70% of the earth's seafloor is composed of soft sediment (Dayton, 2003). Although soft-sediment habitats do not always appear as highly structured as some terrestrial or marine reef habitats, they are characterized by extremely high species diversity. There is now strong evidence of fishing effects on seafloor communities that have important ramifications for ecosystem function and resilience (Rogers et al., 1998; Steneck, 1998; Dayton, 2003). Given the magnitude of disturbance by *trawling* and *dredging* and the extension of fishing effort into more vulnerable benthic communities,

Figure 1: **Distribution of major estuaries around the world**

Modified from: MA, 2005b

this type of human disturbance is one of the most significant threats to marine biodiversity (Dayton, 2003). Sponge gardens in soft substrates face particular threat from bottom trawling, since the soft substrate is easily raked by heavy trawling gear (MA, 2005).

Apart from their extremely high species diversity, soft-sediment marine organisms have crucial functional roles in many biogeochemical processes that sustain the biosphere (Dayton, 2003). Within the sediments, microbial communities drive nutrient recycling. In addition, the movement, burrowing, and feeding of organisms such as worms, crabs, shrimps, and sea cucumbers, markedly increase the surface area of sediment exposed to the water column. This affects nutrient recycling back into the water column, where it can again fuel primary production. Organic debris produced on the continental shelf finds its way to the shelf edge, where it accumulates in canyons that act as sinks to the deep ocean. There, it supports extremely high densities of small crustaceans that in turn serve as prey for both juvenile and mature fish (Vetter and Dayton, 1998).

The ocean floor's soft sediment is interrupted by highly structured seamounts with highly diverse communities of organisms (Dayton, 1994). These underwater mountains or volcanoes are usually found far offshore and are thought to be crucial for many pelagic fish species. They are sites for breeding and spawning, as well as safe havens for juvenile fishes seeking refuge from open ocean predators (Johannes et al., 1999). Because their high species diversity is concentrated into a relatively small, localized area, and because of their occasionally high endemism, sea mounts are extremely vulnerable to fishing impacts.

Coral reefs

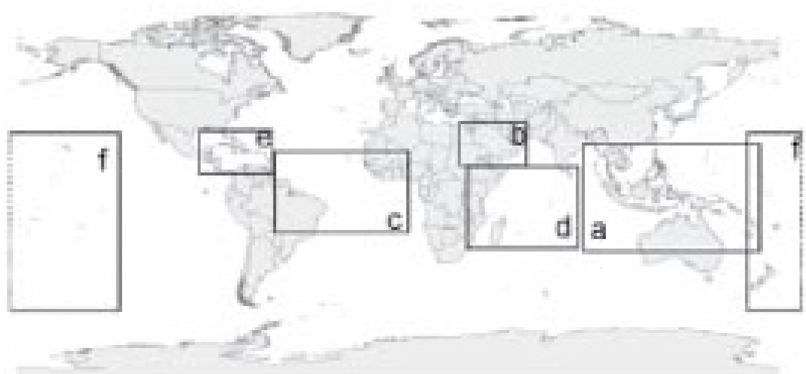
Coral reefs exhibit high species diversity and endemism and are valued for their provisioning, regulating, and cultural services (McKinney, 1998). Reef-building corals occur in tropical coastal areas with suitable light conditions and high salinity, and are particularly abundant where sediment loading and freshwater input is minimal. The distribution of the world's major coral reef ecosystems is shown in Figure 2. Reef formations occur as barrier reefs, atolls, fringing reefs, or patch reefs, and many islands in the Pacific Ocean, Indian Ocean and Caribbean Sea have extensive reef systems occurring in a combination of these types. Coral reefs occur mainly in relatively nutrient-poor waters of the tropics, yet because nutrient cycling is very efficient on reefs, and complex predator-prey interactions maintain diversity, productivity is high. However, with a high number of trophic levels, the amount of primary productivity converted to higher levels is relatively low, and reef organisms are prone to overexploitation.

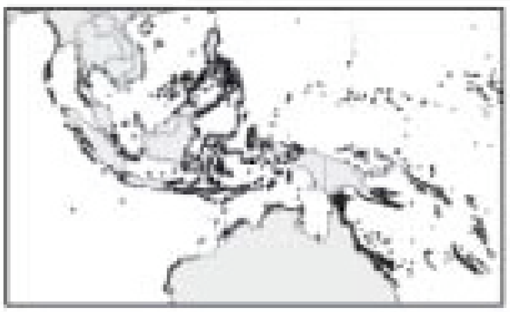
The fine-tuned, complex nature of reefs makes them highly vulnerable to negative impacts from over-use and habitat degradation. When particular elements of this interconnected ecosystem are removed, negative feedbacks and cascading effects occur (Nystrom et al., 2000). Birkeland (2004) describes ecological ratcheting effects through which coral reefs are transformed from productive, diverse biological communities into depauperate ones, and similar cascading effects caused by technological, economic, and cultural phenomena. Coral reefs are one of the few marine ecosystems displaying disturbance-induced phase shifts. This phenomenon causes diverse reef ecosystems dominated by stony corals to dramatically turn into biologically impoverished wastelands overgrown with algae (Bellwood et al., 2004). Reefs are highly vulnerable to being negatively affected by global warming; rising sea temperatures cause coral bleaching, and often subsequent mortality.

Seagrass beds

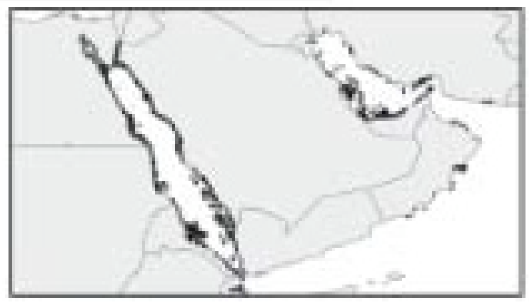
Seagrass is a generic term for the flowering plants that usually colonize soft-bottomed areas of the oceans from the tropics to the temperate zones (some seagrass can be found on hard-bottomed areas but the areas occupied are usually small). In estuarine and other nearshore areas of the higher latitudes, eelgrass (e.g. *Zostera spp.*) forms dense meadows (Deegan and Buchsbaum, 2001). Further towards the tropics, manatee and turtle grass (e.g. *Thalassia testudinum* and *Syringodium filiforme*) cover wide areas. These popular names are due to the important role seagrass plays as the main food source of these

Figure 2: Global distribution of major coral reefs



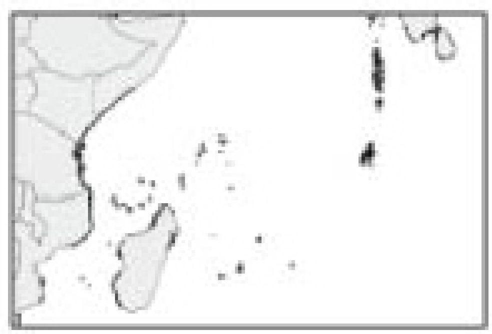


(a) East Indian and Western Pacific Oceans



(b) Middle East

(c) South Atlantic



(d) West Indian Ocean

(e) Caribbean

(f) Oceania

Modified from: UNEP-World Conservation Monitoring Centre, 2003 large, herbivorous vertebrates. Along with mangroves, seagrass is thought to be particularly important in providing nursery areas in the tropics, where it provides crucial habitat for coral reef fishes and invertebrates (Gray et al., 1996; Heck et al., 1997). This is a highly productive ecosystem, and an important source of food for many species of coastal and marine organisms in both tropical and temperate regions (Gray et al., 1996). Seagrass also plays a notable role in trapping sediments and stabilizing shorelines.

Seagrass continues to play an important ecological role even once the blades of grass are cut by grazers or currents and are carried by the water column. Drift beds, composed of mats of seagrass floating at or near the surface, provide important food and shelter for young fishes (Kulczycki et al., 1981). In addition, the deposit of seagrass castings and macroalgae remnants on beaches is thought to be a key pathway for nutrient provisioning to many coastal invertebrates, shorebirds, and other organisms. For instance, nearly 20% of the annual production of nearby seagrass (over 6 million kg dry weight of beach cast) is deposited each year on the 9.5 km beach of Mombasa Marine Park in Kenya, supporting a wide variety of infauna and shorebirds (Ochieng and Erftemeijer, 2003).

Tropical seagrass beds or meadows occur both in association with coral reefs and removed from them, particularly in shallow, protected coastal areas such as Florida Bay in the United States, Shark Bay and the Gulf of Carpentaria in Australia, and other geomorphologically similar locations. Seagrass is also pervasive (and ecologically important) in temperate coastal areas such as the Baltic Sea (Fonseca et al., 1992; Isaakson et al., 1994; Green and Short, 2003).

Offshore Open Water

The largest marine habitat by area or volume is offshore open water. This accounts for close to 55% of the earth's surface, providing nearly 90% of the living space of the biosphere. This offshore open water is not homogenous, however. Ocean circulation creates both pelagic water masses and dynamic frontal zones, both of which influence the distribution of communities of marine organisms. In the Mediterranean Sea, for instance, a frontal zone and associated upwelling area in the Ligurian Sea is distinctive because of the large diversity of marine mammals and other marine animals that congregate there to feed (see NCEP case study on *The Pelagos Sanctuary for Mediterranean Marine Mammals*).

The water column habitats of the world ocean can be subdivided into *biomes*. Although marine biogeographers have long struggled to classify the oceans according to not only the physical environment but also the biotic one, much as the Udvardy classification of terrestrial ecosystems, today the most widely accepted system is that of Longhurst (1998) who divides the world ocean into four major biomes (see Figure 3).

The Coastal Boundary Zone biome (10.5% of the world ocean) consists of the continental shelves (0-200 m) and the adjacent slopes, i.e., from the coastlines to the oceanographic front usually found along the shelf-edges (Longhurst, 1998). From a conservation point of view, this is the most important portion of the world ocean, since this is where human uses of, and impacts on, marine resources is the greatest.

The Trade-winds biome (covering 38.5% of the world's oceans) lies between the boreal and austral Subtropical convergences, where a strong density gradient hinders nutrient regeneration. The resulting low levels of new primary production make these zones the marine equivalent of deserts (MA, 2005c). Therefore, fisheries in this biome rely mainly on large pelagic fishes, especially tunas, capable of migrating over the long distances that separate isolated food patches. In the eastern tropical Pacific, a major portion of the tuna purse-seine catch results from exploitation of a close association with pelagic dolphins, which suffered severe depletion due to incidental kills in the tuna seines (Gerrodette, 2002). One exception to the general low productivity of the Trade-winds biome is around islands and seamounts, where physical processes such as localized upwelling allow for localized enrichment of the surface layer. Above seamounts, these processes also lead to the retention of local production and the trapping of advected plankton, thus turning seamounts into oases characterized by endemism and, when pristine, high fish biomass.

In the Westerlies biome (35.7% of the world's oceans), seasonal differences in mixed-layer depth are forced by seasonality in surface irradiance and wind stress, inducing strong seasonality of biological processes, characteristically including a spring bloom of phytoplankton (MA, 2005c). The fisheries of this biome, mainly targeting tuna and other large pelagics, are similar to those of the Trade winds biome.

The Polar biome covers 15% of the world ocean and accounts for 15% of global fish landings. The noteworthy productivity of this biome results from vertical density structure determined by low-salinity waters from spring melting of ice. The bulk of annual primary production occurs in ice-free waters as a short intense summer burst. Primary production under lighted ice occurs over longer periods, especially in Antarctica. The Antarctic krill, *Euphausia superba*, consumes the primary producers from both open waters and under the ice and then serves as food for a vast number of predators, notably finfishes, birds (especially penguins), and marine mammals (MA, 2005c).

Marine Ecology

Marine Population Ecology

Life history

Conservation and restoration decisions rest on understanding the processes that result in population changes, ecosystem stability, and succession. There are important thresholds in populations and ecosystems, relating to critical stages in the life histories of the populations, as well as to the roles populations play with regard to the resiliency of the ecosystems to natural and anthropogenic stress.

For marine systems such questions have focused on recruit-

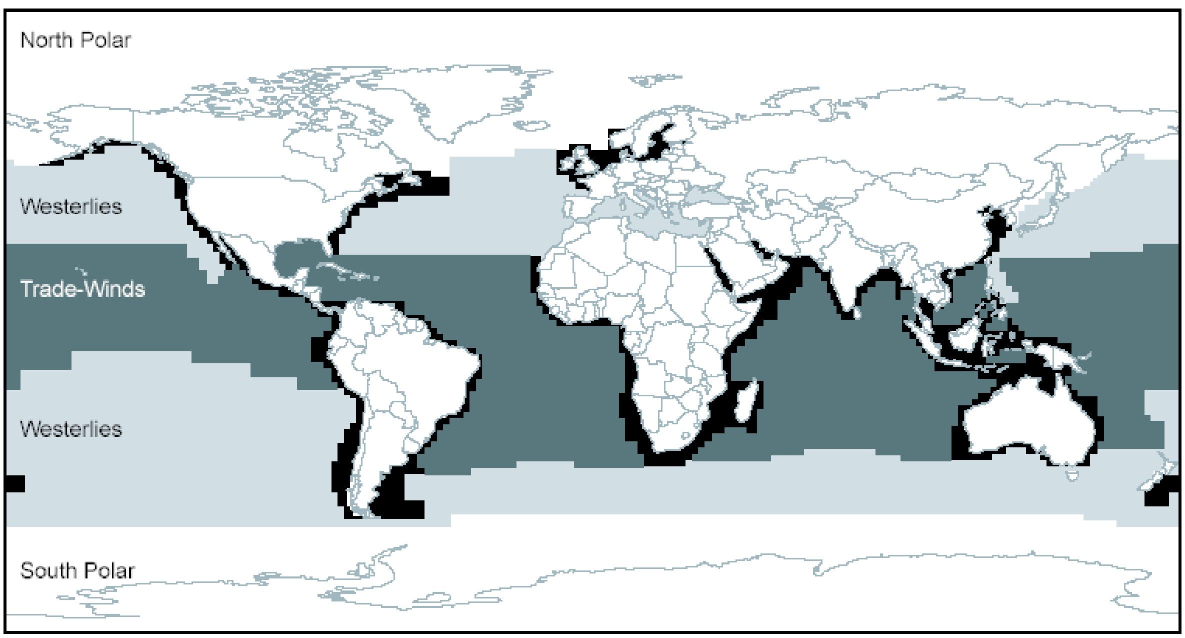


Figure 3: Longhurst classification of ocean biomes
The coastal boundary is indicated by a black border around each continent. Each of these biomes is subdivided into Biogeographical Provinces (BGP). The BGP of the coastal boundary biome largely overlaps with the LEMs identified by K. Sherman.

Taken from: MA, 2005c, adapted from Longhurst, 1998 ment dynamics, and while there are also many higher order processes such as productivity and turnover rates, understanding recruitment constitutes a logical beginning towards comprehending population and ecosystem thresholds (Dayton, 2003). Variously defined, ecologists have attempted to identify sources, sinks, and essential habitats as important factors of recruitment processes. Despite definitions, questions remain: how does one operationally define sources and sinks or rank habitat qualities? How can habitats be placed along a source-sink gradient? Critical periods and thresholds or bottlenecks can vary in time and space: how do we rank and study them with regard to declining populations and fragile ecosystems without understanding the relevant natural history? In most marine systems the following life-history components are important and have distinct thresholds (Dayton, 2003).

Reproduction

Fertilization of gametes is essential, and tactics for achieving this are well known for the birds and bees of the terrestrial world. Fertilization tactics are often very different in the sea, however, where dilution of gametes for broadcast spawners implies that individuals must release sperm and eggs within a meter or so of each other (Tegner et al., 1996). Fertilization of relatively sedentary species such as abalone, scallops, sea urchins, and bivalves often depends on the existence of dense patches of males and females, or en masse spawning. The *Allee effect* describes the relationship between high numbers of reproducing adults and successful subsequent recruitment of young – in some systems, management must take these Allee effects into account. In many cases, the feature that attracts spawning aggregations is a biologically produced physical structure, such as a coral reef. For example, Koenig et al. (1996) report that Florida groupers traveled over 100 miles to gather around deep-water Oculina coral reefs to spawn. Similar roles are likely to be played by other deep-water coral reefs, most of which have been virtually obliterated in the Aleutian Islands, Nova Scotia, Scotland, Norway, and especially the Southern Ocean seamounts.

How particular species are adapted to ecological conditions, including predation pressure and competition, is important for conservation and management (Dayton, 2003). As on land, marine species exhibit a wide variety of fertility patterns, which can be categorized as either R- or K- selected. R-selected species have high fertility and are usually free-spawning, with little to no parental care. K-selected species have significantly lower fertility (and usually longer life spans), but exhibit brooding and more parental care.

Larval ecology and recruitment

Critical periods in the planktonic life of fish and other marine larvae include time of first feeding, successful dispersal to appropriate habitats, settlement, and metamorphosis (Hjort, 1914). The first feeding periods are defined by the abilities of the larvae to handle prey, as well as sufficient density of appropriate prey. Invertebrates have much more complicated life history patterns and dispersal tactics, with post-fertilization and dispersal processes varying from seconds for brooding species, to many months for organisms with feeding larvae.

Most *propagules* depend on oceanographic transport. The larvae of most species with planktonic dispersal drift for periods of 3 to 60 days. Because of complicated coastal oceanography, the differences within this period of time often encompass complex and very different physical transport systems. This is especially true in the very near shore areas. These include those within/between bays, kelp forests, or unstable *gyres* where "relaxation" modes are important, and the oceanography is complicated. The variability in these factors complicates the definition of sources and sinks for species such as lobsters, and some echinoderms with very long larval periods (Dayton, 2003).

Dispersal processes are highly variable in evolutionary adaptations and the physical transport systems they utilize. Marine ecologists often focus on dispersal biology, but many systems, such as the clonal encrusting ones, have virtually no dispersal (Dayton, 2003). Most reproduce by budding or crawl-away larvae (Levin et al., 2001). In the same sense, many other soft-bottom groups including peraicarid crustacea and capitellid polychaetes are brooders and disperse as adults; their transport systems include the bottom *flocculent layer* or being picked up and carried by complicated breaking internal waves.

Successful settlement is another critical period (Tegner and Dayton, 1977). Food availability and temperature strongly influence the length of time spent in the water column. The period at which a larva becomes capable of settlement is known as the competent phase. The larva may continue to drift, exposing itself to increased risk of predation before it settles. Models of Jackson and Strathmann (1981) demonstrate that critical parameters are mortality rates, the length of the precompetent period, and the ratio of competent/precompetent time. These factors are poorly understood but extremely important and probably account for the common observation of episodic settlement.

Availability of appropriate settlement habitats or nurseries can be an important bottleneck, and much is left to chance (Sale, 1991). Many unanswered questions remain about how young locate appropriate settlement areas, especially those species that show natal homing. For instance, much as sea turtles return to the nesting beach where they were hatched in order to lay eggs, coral larvae also must find the reef after planktonic drifting. Recent research suggests that sound may have a role to play in coral settlement (Simson et al., 2005). Environmental inducements are sometimes needed for larvae to settle and metamorphose. According to Dayton, species with the longest precompetent periods also have very specific recruitment habitats that help avoid predation, disturbance, and stress (Dayton et al., 1995).

Indian lionfish (*Pterios muricata*) off of the Seychelles (Source: K. Frey)

Juveniles and adults often have different habitats. For example, nurseries of many Pacific rockfish are in kelp forests, and many other species rely on sea grass beds, mangroves, corals, various associations of encrusting species, or depressions in soft bottom habitats. In many cases the adults live in very different habitats and migration may be tenuous and risky. Without understanding this natural history, artificial settlement areas such as man-made reefs may simply be killing zones if the appropriate adult habitats are not available.

Community Ecology

Communities of organisms, whether in the sea or on land, respond in predictable ways to the forces of interspecific and intraspecific predation and competition. The intertidal communities of temperate regions provided many of the experiments that led to this understanding: most famous of all were the studies by Paine and colleagues, who removed the top predator *Pisaster* (a species of sea star) from intertidal rock pools and observed the decline in species diversity that resulted (see Paine, 2002, for a review of earlier studies and new results). Removal of predators can have this effect because top predators keep their prey populations down in number so that none can dominate. When this sort of predation pressure stops, species that were formerly controlled by predator populations are "released" and multiply, upsetting the original biodiversity balance. When such perturbations cause effects across the entire food web, they are known as "cascading effects," because impacting the top trophic level subsequently impacts the trophic levels below it.

Kelp forest communities are well studied in regards to cascading effects. At the bottom of the kelp community food web are seaweeds (kelps and other algae) and microscopic planktonic algae, both of which serve as the primary producers in this ecosystem. The planktonic algae support small planktonic invertebrates such as copepods, which in turn are consumed by filter-feeding sessile invertebrates such as hydroids, scallops, barnacles, sea anemones, bryozoans, and tube worms, as well as other smaller mobile predators like fish and certain crustaceans. The larger seaweeds are eaten both directly by a broad range of animals, including sea urchins, fishes, small snails, shrimp-like crustaceans, sea stars, and crabs, and indirectly (as large and small loose pieces of "drift") by abalones, sea urchins, mussels, and barnacles. Many of these animals are then consumed by mid-level predators, such as other sea stars, larger crabs, larger fishes, and octopuses.

The sea otter, at the top of the food web, acts as a "keystone species" in the community. Keystone species are ones that have, for various reasons, a substantial effect—disproportionate to their numbers—on the rest of the community. Because they lack the blubber of other marine mammals, individual sea otters need to consume a huge amount of food each day to stay warm and healthy. While a population of otters may eat many things, sea urchins are their favorite prey. Since sea urchins can have major effects on other species in the community, otter predation on them exerts a controlling influence on the ecosystem. When otters are removed from the community, or their numbers are diminished, urchin barrens can result, where urchins graze down everything including the kelp that provides the foundation for the other species to live (this effect is described in the *Introduction to Marine Conservation Biology* exercise; students are asked to predict what the effect of sea otter removal might be).

Predator/prey relations are thus important to understanding how communities of organisms are structured, and how populations of those organisms are maintained. Competition is also important, though probably a less dominant force in most marine communities. But impacts on community ecology are not only the result of perturbations involving predators – they can be felt with the removal of herbivores (or grazers) as well. In a recent study on coral reef community ecology in the Bahamas, Mumby (2006) studied the effects of removing parrotfish on the health and diversity of reefs across a wide area. Removing even small numbers of these grazers can have dramatic effects on reef communities, influencing the amount of coral cover, biomass of reef species, and reef species diversity. The reason for this is that herbivores like parrotfish keep algae from overgrowing the reef and diminishing the availability of niches for other reef species (including corals, sponges, crustaceans, mollusks, and fishes).

These community effects seem most pronounced in ecosystems that are relatively closed systems, and where food is a key limiting factor. In more open systems in which food is readily available, such as major upwelling systems like the Benguela or Peruvian upwellings, removal of one species likely has less discernable effects. But even open ocean systems can see dramatic changes to communities as a result of disturbance – for example, "trophic mining," in which industrial fisheries remove whole swaths of a trophic level and change the energetics of the entire community (Pauly et al., 1998).

Understanding why populations decline or why natural communities are disrupted is a critical facet of conservation. With well-studied ecosystems like coral reefs and kelp forests, the effects of perturbation can be anticipated. But even with well-studied communities, questions remain. And many, many ecological communities are not well studied at all.

Populations decline for a variety of reasons, and ecologists have debated the processes determining the distribution and abundance of individuals within populations. The debate includes disputes about the relative roles of density independent and dependent factors, the importance of interspecific and intraspecific competition, predation, parasites, and mutualistic relations. Dayton (2003) suggests the following list as a small sample of some of basic issues that need to be addressed in marine conservation biology.

Cumulative effects:
- How much is too much? What defines limits and thresholds?

- What describes species vulnerability?
- Are some species redundant and expendable?
- Can cumulative impacts of human perturbations be predicted?

Ecosystem or habitat stability and recoverability:
- How do we define and measure stress in multispecies systems?
- How do we define habitat or ecosystem health?
- Why do systems collapse? What are the thresholds?
- What are the processes that maintain stability?
- What are the processes that define recoverability?

Trend analysis:
- How do we differentiate human induced-trends from natural trends?
- What determines whether trends are general or peculiar to particular systems?
- What spatial and temporal scales are necessary for such trend analysis?
- How can society acquire trend data from already peturbed systems?

Restoration Ecology:
- How to define the desired state?
- What are realistic goals? How are they determined?
- How should we manipulate successional processes that are little understood?
- What are the most efficient means of restoration?

This extensive list of research questions demonstrates how little we actually know about marine community ecology, and how far behind the study of terrestrial ecology marine science lags. In some sense conservation is hindered by these gaps in knowledge and most management focuses on the simplest impacts. But innovative new management measures do allow applied information to be gained quickly through the process of adaptive management – and these approaches help overcome information constraints. Marine conservation will be greatly aided in coming years if applied research is directed at solving these basic questions.

Marine Resource Use and Conservation

Marine Resource Use

Coastal ecosystems are among the most productive, yet highly threatened systems in the world. They comprise heavily used coastal lands, areas where freshwater and saltwater mix, and nearshore marine areas. These ecosystems produce disproportionately more services relating to human well-being than most other systems, even those encompassing larger total areas. At the same time, these ecosystems are experiencing some of the most rapid environmental change: almost half of the world's mangroves have been lost or converted, and approximately 27% of coral reefs have been destroyed globally in the last few decades. Coastal wetland loss in some places has reached 20% annually (MA, 2005b).

Coastal areas are experiencing growing population and exploitation pressures; nearly 40% of the world population lives in this thin fringe of land (MA, 2005b). Demographic trends suggest coastal populations are rapidly increasingly, mostly through migration, increased fertility, and tourist visitation to these areas. Population densities on the coasts are nearly three times that of inland areas. Communities and industries increasingly exploit fisheries, timber, fuelwood, construction materials, oil, natural gas, sand and strategic minerals, and genetic resources. Additionally, demand on coastal areas for shipping, waste disposal, military and security uses, recreation, aquaculture, and even habitation are increasing.

Shoreline communities aggregate near those types of coastal systems that provide the most ecosystem services (MA, 2005b). These subtypes are also the most vulnerable. Within the coastal population, 71% live within 50 km of estuaries. In tropical regions, settlements are concentrated near mangroves and coral reefs. These habitats provide protein to a large proportion of the human coastal populations in some countries. Coastal capture fisheries yields are estimated to be worth a minimum of USD 34 billion annually. Marine ecosystems provide other resources as well: building materials (e.g., sand, coral), ores, and energy (hydrocarbons, thermal energy, etc.).

Marine systems also provide pharmaceuticals, and are highly valued for recreational, spiritual, and cultural reasons.

Sub-national sociological data suggest that people living in coastal areas experience higher well-being than those living in inland areas. The acute vulnerability of these ecosystems to degradation, however, puts these inhabitants at greater relative risk (MA, 2005b). The world's wealthiest populations occur primarily in coastal areas (per capita income being four times higher in coastal areas than inland). It is thought that life expectancy is higher, while infant mortality is lower, in coastal regions. However, many coastal communities are politically and economically marginalized, and do not derive the economic benefits from these areas. Wealth disparity has led to the limitation of access to resources for many of these communities. Access issues have in turn led to increased conflict, such as between small-scale artisanal fishers, and large-scale commercial fishing enterprises. Regime shifts and habitat loss have led to irreversible changes in many coastal habitats and losses in some ecosystem services. Finally, many degraded coastal systems are near thresholds for healthy functioning, and they are simultaneously vulnerable to major impacts from sea level rise, erosion, and storm events. This suggests that coastal populations are at risk of having their relatively high levels of human well-being severely compromised.

Threats to Marine Ecosystems and Biodiversity

General

Human pressures on coastal resources are compromising many of the ecosystem services crucial to the well-being of shoreline economies and peoples. While the ocean comprises nearly three-quarters of the Earth's surface area, it accounts for nearly 99% of its habitable volume. Thus, disruptions of marine and coastal ecosystem services have global consequences. Coastal fisheries have depleted stocks of finfish, crustaceans, and mollusks in all regions (MA, 2005b). Illegal and destructive fisheries often cause habitat damage as well as over-exploitation. Large scale coastal fisheries deprive shore communities of subsistence, and are causing increasing conflicts, especially in Asia and Africa (MA, 2005c). Demands for coastal aquaculture have been on the rise, partly in response to declining capture fisheries. The doubling of aquaculture production in the last 10 years, however, has also driven habitat loss, overexploitation of fisheries for fishmeal and fish oil, and pollution. Over-exploitation of other resources, such as mangrove for fuel wood, sand for construction material, seaweeds for consumption, etc., also often undermine the ecological functioning of these systems.

The greatest threat to coastal systems is development-related loss of habitats and services. Many areas of the coast are degraded or altered, such that humans are facing increasing coastal erosion and flooding, declining water quality, and increasing health risks. Port development, urbanization, resort establishment, aquaculture, and industrialization often involve destruction of coastal forests, wetlands, coral reefs, and other habitats. Historic settlement patterns have resulted in centers of urbanization near ecologically important coastal habitats. About 58% of the world's major reefs occur within 50 km of major urban centers of 100,000 people or more, while 64% of all mangrove forests and 62% of all major estuaries occur near such urban centers. Dredging, reclamation, engineering works (beach armoring, causeways, bridges, etc.) and some fishing practices also account for widespread, usually irreversible, destruction of coastal habitats (MA, 2005b).

Degradation is also a severe problem, since pressures within coastal zones are growing and these areas are also the downstream recipients of negative impacts of land use. Freshwater diversion from estuaries has meant significant losses of water and sediment delivery (30% decrease worldwide, with regional variations) to nursery areas and fishing grounds (MA, 2005b). The global average for nitrogen loading has doubled within the last century. This has made coastal areas the most highly chemically altered ecosystems in the world, with resulting eutrophication that drives coral reef regime shifts and other irreversible ecosystem changes. Nearly half of the global population living along the shore has no access to sanitation, and thus faces decreasing ecosystem services and increasing risks of disease (UNEP, 2002). Mining and other industries cause heavy metal and other toxic pollution. Harmful algal blooms and other pathogens, which affect the health of both humans and marine organisms, are on the rise. This can partly be attributed to decreased water quality. Invasions of alien species have already altered marine and coastal ecosystems, threatening ecosystem services.

The health of coastal systems and their ability to provide highly valued services is intimately linked to that of adjacent marine, freshwater and terrestrial systems, and vice versa. Land-based sources of pollutants are delivered via rivers, from run-off, and through atmospheric deposition. These indirect sources account for the large majority (77%) of pollutants (MA, 2005b). In some areas, pollution in coastal zones contaminates groundwater; this is a particular threat in drylands (MA, 2005b). Another linkage occurs between expanding desertification and pollution of coral reef ecosystems caused by airborne dust. Destruction of coastal wetlands has similarly been implicated in crop failures due to decreased coastal buffering leading to freezing in inland areas.

Though habitat conversion is the main driver behind coastal biodiversity loss, overexploitation of resources and, on continental shelves, fisheries-related habitat destruction, degradation driven by pollution, invasive species, and climate change play major roles. Trophic cascades and trophic mining result from overexploitation of fishery resources. This leads to biodiversity losses at the genetic, population, and even species levels. Marine ecosystems are less able to provide important ecosystem services (especially provisioning services) and often are less resilient as a result (MA, 2005b). Many of these impacts create negative synergies, in which multiple and cumulative impacts cause greater change to ecosystems and services than the sum of individual impacts would predict. At the same time, all ecosystems and the biodiversity they support are subject to multiple and cumulative impacts, both natural and anthropogenic. Some ecosystems face greater numbers of threats than others, particularly those that support a wide variety of uses/services (e.g. coastal ecosystems, islands). One effect of multiple impacts occurring simultaneously is to alter thresholds and increase the non-linearity of response (thus decreasing the predictability of environmental change) (MA, 2005a).

In addition to the proximate drivers, indirect drivers are behind each of these impacts. Population growth is said to be the main indirect driver behind all environmental change today. The link between sheer population number and environmental quality is not clear cut, however. Some authors argue that a direct link exists between the number of people and the quality of the environment or loss of diversity, irregardless of consumption patterns (McKee et al., 2004). Others argue that the number of households is better correlated to the environmental impact or *ecological footprint* left by humans (Liu et al., 2003). In the coastal zone, however, neither population numbers nor household numbers tell the full story. Patterns of consumption and other human behaviors greatly influence the ecological footprint left by communities, and migration and its effects often spell the difference between sustainable and unsustainable use (Curran and Agardy, 2002; Creel, 2003). Local resource use and migration patterns are also affected by local and international markets.

Habitat Loss and Degradation

The most serious consequences of biodiversity loss occur when changes are irreversible: e.g. habitat loss (especially complex habitats), species extinction, population extirpation, regime shifts. The most important driver behind these large scale impacts on biodiversity is land conversion (including coastal/marine habitat loss). However, the main drivers behind biodiversity loss are different in various ecosystems. The risks of abrupt/non-linear changes in species composition and the corresponding risks of abrupt or non-linear changes in ecological systems vary by species and ecosystem. Although natural systems contain significant redundancy in terms of ecological roles that species play in providing ecosystem services, there is no doubt that major decreases in species diversity (and thus the complexity of interactions between species) lead to potentially unstable, though often productive, ecosystems. Removal of species can cause cascading effects that alter productivity at various trophic levels. Such cascading effects are most acute when keystone predators are removed (see Finke and Denno, 2004 on predator diversity dampening trophic cascades, for example).

While the threat of greatest magnitude to coastal systems is development-related conversion of coastal habitats, degradation is a severe problem for biodiversity, since pressures within coastal zones are growing and because coastal zones are the downstream recipients of negative impacts of land use. Freshwater diversion from estuaries has meant catastrophic losses of water and sediment delivery (30% decrease worldwide) to nursery areas and fishing grounds. At the same time, external inputs lead to loss of biodiversity, reduction of ecosystem services, and declines in human well-being, especially in coastal communities.

Resource Extraction

Fishing and other extraction activities affect the stocks of living and non-living resources, the things that feed or are fed upon by those resources, and the habitat that supports marine life. In general, resource removal is detrimental when the amount of removal is greater than the capacity for the living resource to replenish itself (known as over-exploitation), when the resource being removed has a key role to play in community ecology, or when the method of removal is destructive. In essence, this boils down to three questions: 1) how much removal is sustainable?; 2) which resources can be removed sustainably?; and 3) how can resources be removed sustainably? (i.e. by what methods?).

While it would appear that significant concerns about fisheries impacts on the marine environment exist, most concern over the environmental effects of fishing has focused on near-shore habitats. In fact, the vast scope of ecological destruction of the full suite of marine habitats has only recently been documented. The removal of small-scale heterogeneity associated with the homogenization of habitats is an important cause of the loss of biodiversity in many marine systems (Dayton, 2003). And restoration of the system depends upon an understanding of structure in time and space, and of biological thresholds for all of the species that create and maintain the structure (Dayton, 2003).

There is now strong evidence of fisheries effects on seafloor communities that have important ramifications for ecosystem function and resilience. Given the magnitude of disturbance by trawling and dredging and the extension of fishing effort into deeper, more sensitive benthic communities, this type of human disturbance is one of the most significant threats to biodiversity and the provision of ecosystem services (Thrush and Dayton, 2002).

Invasive Species (Including Pathogenic Diseases)

Invasion of coastal and marine areas by non-indigenous or alien species is a major threat to marine biodiversity and ecosystem functioning, much as invasions are causing major ecological changes on land. Altering soft bottom habitat to hard bottom in the process often affects estuaries indirectly by creating conditions for new assemblages of species, and facilitating range expansions of invasive species (Ruiz and Crooks, 2001). The resulting ecosystems may have losses in some ecosystem services and biodiversity. In New Zealand invasive species have displaced commercially important mussel beds, resulting in significant economic losses for many mussel farmers (NOAA News Online, 2003).

Estuarine systems are among the most invaded ecosystems in the world, with exotic introduced species causing major ecological changes (Carlton, 1989, 1996). Often introduced organisms change the structure of coastal habitat by physically displacing native vegetation (Harris and Tyrrell, 2001; Grosholz, 2002; Murray et al., 2004). For example, San Francisco Bay (U.S.A.) has over 210 invasive species, with one new species established every 14 weeks between 1961 and 1995 (Cohen and Carlton, 1995, 1998). Most of these bio-invaders were borne by ballast water of large ships or occur as a result of fishing activities (Carlton, 2001). The ecological consequences of the invasions include: habitat loss and alteration; altered water flow and food webs; the creation of novel and unnatural habitats subsequently colonized by other exotic species; abnormally effective filtration of the water column; hybridization with native species; highly destructive predators; and introductions of pathogens and disease (Ruiz et al., 1997; Bax et al., 2003).

Climate Change

The geographically largest scale impacts to coastal systems are caused by global climate change, and since rates of warming are generally expected to increase in the near future, projected climate change-related impacts are also expected to rise (IPCC, 2003). Warming of the world's seas degrades coastal ecosystems and affects species in many ways: by changing relative sea level faster than most biomes can adapt; by stressing temperature-sensitive organisms such as corals and causing their death or morbidity (in corals this is most often evidenced by coral bleaching); by changing current patterns and thus interfering with important physiobiotic processes; and by causing increased incidence of pathogen transmission (MA, 2005b). Coral reefs may be the most vulnerable, having already evidenced rapid change, and some projections predict the loss of all reef ecosystems this century (Hughes et al., 2003). Global warming also changes the temperature and salinity of *estuary* and nearshore habitats, making them inhospitable to species with narrow temperature tolerances. Warming can also exacerbate the problem of eutrophication, leading to algal overgrowth, fish kills, and dead zones (Burke et al., 2001). Finally, warming is expected to further increase the transmission rates of pathogens and hasten the spread of many forms of human and non-human disease.

Climate change-related sea level rise will cause continued inundation of low-lying areas, especially in areas where natural buffers have been removed (Church et al., 2001). Sea level rise is due to thermal expansion of ocean waters and melting of land-based ice, and both expansion and ice melts are expected to increase (IPCC, 2003). In most if not all cases, global climate change impacts act in negative synergy with other threats to marine organisms, and can be the factor sending ecosystems over the threshold levels for stability and productivity. In limited cases, new habitats may be created. Changes in weather patterns modeled in some extreme scenarios of climate change, including increased precipitation in some areas, abrupt warming at the poles, and increased frequency and intensity of storm events, would affect oceanic circulation (perhaps even leading to the collapse of thermohaline circulation) and currents, and the ability of organisms to live or reproduce.

Most Threatened Areas

Island systems are especially sensitive to disturbances, and island biota particularly vulnerable to extinction, primarily driven by ecological changes wrought by invasive species. Many islands serve as important biological *refugia* for species that are either extinct or threatened on nearby continental landmasses. The habitat destruction and biodiversity loss on islands may therefore have more immediate and serious repercussions than on continental systems. With growing population and exploitation pressures, the impact on some island systems has exceeded the critical point. Invasive species are one of the most significant drivers of environmental change to islands over the world, and oceanic islands are more successfully invaded by vertebrates compared to corresponding continental areas.

Nearshore areas are particularly vulnerable to anthropogenic threats. The destruction of the natural watershed often results in the loss of most of the attributes of estuarine habitat, for instance. Poor management of watersheds, including poor grazing practices that destroy natural *riparian* habitats, results in floods and burial of the natural habitats under silt and enriched sediment. Often these impacts combine with severe nutrient loading, causing large coastal areas to become anoxic. An extreme example is the massive (up to 15,000 km^2) dead zone in the Gulf of Mexico (Turner and Rabalais, 1994). Urbanization of watersheds interrupts the flow of both essential fresh water and nutrients. Nutrient loading and eutrophication result in prolonged ecological degradation, as algae take over bottom habitats and the water column so that the entire ecosystem is altered (Levin et al., 2001).

Coral reefs and the ecosystem services they provide are especially threatened by anthropogenic forces (Birkeland, 2004). Ecosystem services provided by coral reefs include habitat and nurseries for fish, nutrient cycling and carbon fixing in nutrient-poor environments, wave buffering and sediment stabilization, and a number of cultural ecosystem services. These ecosystem services associated with coral reefs can only be maintained if: 1) the ecosystem remains intact, and 2) the interaction between corals and their obligate symbiotic algae is preserved.

Great attention has been paid to the decline in species diversity in terrestrial ecosystems, however it is apparent that there are substantial changes in diversity in deep ocean benthos – albeit changes that may not be so readily detected (Dayton, 2003). Direct killing and habitat loss are primary factors responsible for the global decline in diversity. Most bottom habitats are characterized by biological construction in which the organisms provide structure critical to many other parts of the ecosystem. Examples include reefs of mussels, oysters, sponges, corals (including some 700 species of deep-water corals that may tower more than 40 m above the sea floor), kelp forests, sea grass meadows, and even large single-celled *foraminiferans*, all of which fill important ecological roles within the community (Levin et al., 1986; Rogers, 1999). These roles include filtering the seawater and affecting its flow. The biological structure also serves to retain water masses with larvae, and it furnishes critical habitats and predator protection. The architectural complexity supports a diverse association of feedback loops that define the biological complexity of seafloor processes. These important ecological roles are as yet very poorly understood (Dayton, 2003). Physical disturbance by fishing, mining, etc. can thus significantly impact habitat, species diversity, and interlinked ecological processes.

Methods to Conserve Marine Biodiversity

There are many methods used in marine conservation; indeed, the toolbox is full, though seldom fully utilized. However, many of these tools can be discussed in the context of five major kinds of marine management: 1) spatial management through *marine protected areas*; 2) fisheries management; 3) restoration; 4) integrated coastal management; and 5) international treaties and agreements. These five major themes are presented not by order of importance but rather by the scale at which they are practiced, beginning with the smallest geographical scale and extending to the largest. Truly effective marine conservation requires that these sorts of initiatives be tied together in a holistic manner, so that not only individual sites are protected but the entire context in which such sites lie is protected as well. In many instances, however, a mismatch of scales occurs such that rather than complementing one another, these sorts of methods can impede one another – especially when marine conservation planning is focused only at a particular scale and not the hierarchy of scales that is reality (Agardy, 2005).

Spatial Management Through Zoning and Marine Protected Areas

Individual sites recognized for their valuable services are sometimes protected through zoning regulations and other spatial management interventions, such as marine protected areas (MPAs) (NRC, 2001). Such protected areas may be small fisheries reserves in which resource extraction is prohibited, or they may occur in the context of larger multiple-use areas. Increasingly, marine protected areas are being established in networks in order to safeguard key areas of the coastal and marine environment over a geographically large area (Agardy, 1999; Murray et al., 1999; Pauly et al., 2002). A prime example of this is the network of reserves encompassed by the newly re-zoned Great Barrier Reef Marine Park in Australia (Day, 2002).

In order for marine protected areas to succeed in meeting the objectives of conserving habitats and protecting fisheries and biodiversity, management seeks to address all relevant direct threats. In most habitats, these threats are multiple and cumulative over time. Thus, protected areas that address only one of these will usually fail to conserve the ecosystem or habitats and the services they provide.

Marine and coastal protected areas already dot the coasts of all the world's areas, and the numbers of protected areas continue to increase. The last official count of coastal and marine protected areas in 2003 yielded 4,116 (Spalding et al., 2003). This represents a marked increase over the 1,308 listed in 1995 (Kelleher et al., 1995). It is, however, a significant underestimate because unconventional protected areas that do not fit the IUCN categories for protected areas are typically not counted (see the *Marine Protected Areas and MPA Networks* module). By far the bulk of these protected areas occur in the coastal zone, and many include both terrestrial and aquatic components (MA, 2005b). Even with the large number of individual sites, however, coverage accounts for less than 0.5% of the world's oceans. Many marine protected areas occur in relatively close proximity to human settlements. In fact, nearly ten percent of the global human population lives within 50 kilometers of a marine protected area, and over 25% of the worldwide coastal population lives within 50 kilometers of a marine protected area (MA, 2005b). Management effectiveness of most MPAs remains questionable, and many of these have no operational management or enforced legislation at all. It is well established that marine protected area tools are not being used to their fullest potential anywhere in the world (Agardy et al., 2003).

Fisheries Management

Management of living marine resource use has been practiced for several centuries. Conventional fisheries management relies on fish population dynamics models that suggest *maximum sustainable yield (MSY)* for a particular stock. This information is then used to identify appropriate management regimes such as restrictions on catch (quotas, size limits, age class restrictions, etc.), gear, and harvest time (duration of fishing season). Fisheries managers also look to temporary, seasonal, rotating, or permanent MPAs as a way to target sustainability (MA, 2005c). Determining where to establish fisheries reserves requires an understanding of life histories and determination of essential fish habitat (EFH). These spatial management techniques are most successful in fisheries targeting species whose ecology is well known (Sale et al., 2005). However, even effective management of a single stock or species does not necessarily lead to conservation of the wider community or biodiversity of the region.

Resource use that is managed in a way that considers the impacts that resource removal has on all linked ecosystems and human well-being has proven to be more effective than sectoral or single-species management (Kay and Alder, 2005). Fisheries agencies and conservationists are promoting ecosystem-based fisheries management. This is management that looks at multispecies interactions and the entire chain of habitats these linked organisms need in order to survive and reproduce (Agardy, 2002). Due to the linkages between marine fisheries production and coastal ecosystem condition, the protection of coastal habitats figures very prominently in ecosystem-based fisheries management (Pauly et al., 2002). However, truly holistic integrated management also requires complementary watershed management and land use planning to ensure that negative impacts do not reach these areas from outside the coastal realm.

Implementation of ecosystem-based management (EBM) for fisheries requires a multi-pronged approach. Dinesen and Gribble (2005) explore the dual roles of modeling and policy development in enhancing EBM for Queensland-managed fisheries in Australia. ECOPATH software is used to simulate temporal and spatial reactions to commercial fishing and the imposition of a "no take" zone within an MPA. The addition of spatially explicit habitat data to the equilibrium GBR ecosystem model significantly buffered the predicted volatility in trophic guild biomass, by providing de facto spatial refugia from fishing pressure. The simulations showed that additional protected "no take" zones must be of adequate size to allow for "edge effects" caused by illegal fishing, particularly if sited in remote areas. Fishing tended to concentrate on the borders of the "no take" zone, which produced "gauntlet" effects to the movement of some groups. Vulnerable species did better within "no take" MPA areas, but scavenger/opportunistic species did worse.

Ecosystem-based fisheries management is currently *de rigeur*, even though some fisheries managers profess uncertainty about what the term actually means, and in what ways embracing the concept will change day-to-day operations of fisheries agencies (Lubchenco, 1998). Nonetheless, there are parts of the world where management is moving away from single species or even small-scale multi-species strategies to broader marine management. Many of these initiatives began as a result of regional fisheries agreements (Griffis and Kimball, 1996). A literature has begun to emerge on ecosystem-based fisheries management (e.g., Sinclair and Valdimaarson, 2003).

Arguably, the best example of ecosystem-based marine management is the Convention on Conservation of Antarctic Marine Living Resources (CCAMLR). Many regional fisheries agreements are delimited by the boundaries of large marine ecosystems (LMEs). These are regions of ocean space that extend from inshore to the seaward boundaries of continental shelves and seaward margins of coastal current systems (Kimball, 2001). There are 64 LMEs globally, averaging 200,000 square kilometers, and characterized by distinct *bathymetry*, hydrology, productivity, and trophically-dependent populations (Sherman, 1993; Wang, 2004). The LME concept originated from fisheries management. Even today most of these ecosystems are defined by physical oceanography and fisheries data, and not by other considerations of biodiversity. The LME concept was originally applied in the fisheries context under CCAMLR to take into account predator/prey relationships and environmental factors affecting target stocks. Thus, Antarctica became the first site of a truly ecosystem-based approach to fisheries management, and the target area was defined by the limits of the Antarctic LME. Several recent international instruments refer to LMEs. In addition, the geographic units serve as the basis for some global assessments, such as the UNEP's Global International Waters Assessment (GIWA; www.giwa.org). However, in many parts of the world, the political constituency for nations to cooperate to conserve the large scale ecosystems and marine species they share is limited, though this situation may be improving (Wang, 2004; see the *Marine Protected Areas and MPA Networks* module).

Restoration

Some key coastal habitats, such as mangrove forests, marshes, and seagrass meadows, can be, and are being, restored once degraded. The science of mangrove restoration is relatively advanced. This is especially the case when natural species diversity is low, and replanting a few species can restore ecosystems and most services quickly (Kaly and Jones, 1998). Marshlands are also relatively easily restored, as long as major alterations to hydrology have not taken place. Such initiatives are risky, however, since it has yet to be shown that the full range of ecosystem services can be supported by artificially reconstructed wetlands (NRC, 1992; Moberg and Ronnback, 2003). Coral reef transplantation, though technologically possible, can only be practiced at a small scale, and has had limited success (Moberg and Ronnback, 2003). Furthermore, the costs

Green moray eel (Source: K. Frey)

can be enormous, as the USD 7.8 billion price tag for the restoration of the Everglades cord-grass system in Florida (US) attests. In fact, most full-scale restoration (habitat reconstruction) is practiced in highly developed countries that are able to finance the high costs over the long time frames needed.

Restoration and subsequent management should be based on understanding the sources of propagules of the target species. Understanding propagule sources, however, requires understanding the strong interactions (Sala and Graham, 2002) and definition of target species in most urgent need of management. There is a pressing need to better understand the Allee effect (discussed above) in which sources of propagules, and the thresholds in their respective spawning aggregations, are defined. In addition, it is important to distinguish between larval nurseries and sinks, and establish the relative abundances of each. A clear understanding of successional processes is also important.

Integrated Coastal Zone Management

Complex problems require comprehensive solutions and an integrated management response is needed to conserve most aspects of biodiversity, especially at the ecosystem level. Sectoral approaches have been proven to have shortcomings in management of complex issues such as biodiversity. In marine environments, connectivity over large geographic distances requires a melding of a top-down management approach with the more local and national level approaches typical to most biodiversity conservation.

Integrated management of watersheds, land use planning, and impact assessment are key to protecting coastal ecosystems (Sorenson, 1997). For this reason, tackling the issues of loss and degradation of these areas by addressing single threats has not proven effective in the past. The holistic approach, looking at how human activities affect coastal ecosystems, identification of key threats, and implementation of management that is integrated across all sectors, is a relatively new focus. This is likely to produce much more effective decision-making. Successful management of these crucial areas means coordinated pollution controls, development restrictions, fisheries management, and scientific research.

Significant strides have been made in coastal management in the last few decades, in both the developed and developing world. Many of the earth's 123 coastal countries have coastal management plans and legislation, and new governance arrangements and regulations are being developed every year (Burke et al., 2001). In 1993, it was estimated that there were 142 coastal management initiatives outside the U.S.A. and 20 international efforts (Sorensen, 1993). By 2000, there were a total of 447 initiatives worldwide, including 41 at the global level (Hildebrand and Sorensen, 2001). This dramatic increase in activity was attributed both to new plans implemented since 1993, and to the improved ability to find relevant information using the Internet (Kay and Alder, 2005). The latest survey estimates that there are a total of 698 coastal management initiatives operating in 145 nations or semi-sovereign states, including 76 at the international level (Sorensen, 2002).

Yet even countries with well-developed coastal zone plans that have been in place for decades struggle with over-exploitation of resources, user conflict, habitat loss, and indirect degradation of ecosystems. These may involve activities occurring sometimes hundreds of kilometers away from the focal area. Management has not kept pace with degradation, as the number of interventions worldwide has only increased two or threefold over the last decade. In the same time period, degradation of many habitats, such as coral reefs and mangroves, has increased significantly more (Kay and Alder, 2005). There has been far too much emphasis on process rather than achieving results, and stakeholder participation is often seen as an end in itself instead of a critical step in a larger, more complex process.

Regional and International Agreements/Treaties

Many environmental issues, such as pollution, climate change, protection of marine and freshwater resources, and biodiversity conservation, are large scale topics that require multi-national governmental actions to address them. This is particularly true in the marine context. When resources are shared by more than one country, or consequences result from geographically removed actions, national action alone cannot suffice (Kimball, 2001). Most marine species cross boundaries of individual countries, and the regulation of these resources is beyond the control and responsibility of individual nations. In addition, the oceans contain vast areas that do not fall under the jurisdiction of any nation. These "high seas" are thus a *global commons* that cannot be addressed in any way other than international cooperation and global agreements (see *The Pelagos Sanctuary for Mediterranean Marine Mammals* case study). Such treaties and other agreements are the most frequent means of addressing the conservation of the 'global commons' and worldwide environmental problems. They foster a worldwide conservation ethic where the world's nations strive to conserve marine biodiversity and the environment by working together on global solutions (see the *International Treaties for Marine Conservation and Management* module).

International treaties provide a legal framework for marine conservation action, resource regulation, and scientific research on a broad scale. Such agreements exist at various scales, depending on the nature of the issue and the practicalities of fostering cooperation among countries. Some are global, involving virtually all nations; others are formulated with only those parties having coastal jurisdictions, while still others are regional and involve only countries bordering a particular ocean basin, semi-enclosed sea, or region. Thus, these treaties can be bilateral (between two countries or 'parties') or multilateral (between multiple countries). However, regardless of scale, these agreements legally mandate international cooperation to address complex environmental issues, aiming to promote sustainable utilization and protection of shared natural resources. They form the rules of conduct or behavior agreed upon by the signatory states to take actions that address a conservation and/or environmental issue. In the twentieth century, it has been suggested that environmental treaties are the best means of making law in our diverse world (see the *International Treaties for Marine Conservation and Management* module). But the question of who enforces international law remains a sticking point, and too often national laws are not harmonized to allow international agreement obligations to be carried out.

Global treaties that include all coastal and some riparian nations are crucial in addressing certain marine conservation issues. However, equally important marine agreements exist on the regional scale. Most important among these are the Regional Seas Agreements overseen by the United Nations Environment Programme (UNEP) and various regional fisheries agreements. Regional fisheries agreements such as the International Convention on the Conservation of Atlantic Tunas (ICCAT) allow countries to cooperate in managing shared fish stocks, as well as allowing fisheries management to become more holistic and thus effective by promoting ecosystem-based management approaches.

Constraints To Effective Marine Conservation

Just as marine ecosystems are complex, so do political, social and economic systems exhibit complex non-linear dynamics with thresholds. Social systems are constantly in flux – perhaps even more so than natural ones. Abrupt changes can occur in political (e.g., elections or revolutions), social (e.g., changes in fashions) or economic systems (e.g., technological changes leading to changes in what is produced or how it is produced). For example, an advance in fishing technology from dugout canoes to trawlers with long-line nets and GPS can cause massive changes in rates of resource exploitation. These jumps in exploitation rates often pass the threshold for sustainability, and may result in crashes in fish stocks and other profound alterations in marine ecosystems. These impacts may also be irreversible, since a return to previous low tech methods is unlikely, and fish stocks may be unable to recover even if fishing pressure is subsequently reduced.

Inertia is a fundamental characteristic of socio-economic and natural systems. There is typically a time lag between a perturbation to the system and the complete eventual effects. For example, a reduction in habitat may not result in immediate loss of species in a region. Population levels, however, will fall over time in response to the reduction in habitat. Eventually the population reaches a level where it is no longer sustainable and the species will suffer local extinction. This may occur many decades after habitat reduction (MA, 2005a).

Socio-economic institutions also illustrate considerable inertia. Culture and tradition may make societies reluctant to change practices, even in the face of altered environmental circumstances. Fixed investments in plants, equipment, and infrastructure make fundamental changes in production or consumption costly. New conditions may take place over time as fixed investments wear out and are replaced with new, better adapted investment. In many regions, population pressures on limited land and water resources, government policies impeding flexibility and adaptation, or limited access to information or financial resources make adaptation difficult or slow.

Anticipating major changes is complicated by lags in responses, complex feedbacks between socio-economic and ecological systems, and the difficulty of predicting thresholds prior to such benchmarks being passed. There are a number of intrinsic characteristics of ecosystems and of science that contribute to this. Ecological lag times often mean that responses to changes in biodiversity do not occur immediately; multiple impacts (especially the addition of climate change to the mix of forcing functions) can cause alterations in thresholds; and monitoring methods are often inadequate due to poor choice of indicators, inappropriate periodicity of monitoring, and infrequent analysis of results (MA, 2005a).

A mismatch exists between the dynamics of natural systems and human responses to those changes. Inertia and lag times in both natural and social arenas complicate the ability of humans to anticipate and develop adaptation strategies to cope with change. The result of our current inadequacies in understanding is increasing numbers of "ecological surprises" brought about by voluntary or accidental species introductions or removals. These illustrate how initially small changes in species richness (i.e. often just the addition of one species) can trigger dramatic effects, often with large losses in ecosystem services. For these reasons, conservation is best achieved by focusing on conserving or restoring the composition of communities, rather than simply maximizing species numbers. Particularly important is the preservation of the complex interactions among species, including links between pelagic and benthic organisms, keystone species, ecosystem engineers, and natural enemies of pests and human-disease vectors.

As conservationists, we must come to terms with the fact that considerable uncertainty exists in our understanding of what is in the oceans, how things interact, and how humans use and impact the ocean environment and biodiversity. This uncertainty is sometimes held up as an excuse for inaction – something that civil societies urge decision makers to resist. But the uncertainty can also be harnessed, in a sense, for conservation, by creating the conditions that allow conservationists to promote the precautionary principle. This principle essentially states that in the face of uncertainty, we should err on the side of conservation until better information is gained.

However, there is much political resistance to invoking the precautionary principle, especially in resource management circles that are time-bound by traditional management (especially fisheries management). Another constraint is that though the need to establish management regimes that are designed to further our ecological and sociological understanding is well accepted, developing such adaptive management methods is difficult, time consuming, and potentially costly.

Therefore, incomplete ecological understanding, and corollary incomplete sociological understanding, can be a major constraint in effective conservation. Other constraints include lack of funding for research to bolster that understanding and also funding to undertake monitoring and enforcement of regulations. Perhaps the biggest constraint of all is lack of political will, based in part in the misconception that the oceans are so large that humans could not possibly impact them, and in part in the sense that open access must be preserved in the oceans since they are indeed a global commons

(Agardy, 1997).

Conclusions

Ecological systems are extraordinarily complex and confusing. The populations that compose the systems often respond to environmental factors that are as yet virtually unknown. Yet they must be studied with the classical scientific techniques of simplification, analysis, and synthesis, and testing theory remains the cornerstone of science (Dayton, 2003). A trap exists, however, since bad assumptions can be quantitative and precise, esthetically pleasing, and appear heuristically useful, and experiments might make the right predictions for the wrong reasons (see Dayton and Sala, 2001).

Social systems are also extraordinarily complex. A promising new development in conservation, however, looks at the resilience of social systems as well as ecosystems (Adger et al., 2005). Developments such as these suggest that marine conservation seems at last able to couple human and natural systems and better understand the interactions between the two.

As in the terrestrial literature, the last century has produced a large marine literature. But the value for application to conservation of much of this literature is truncated by the limited appreciation of the important scales in time and space. While the focus on small scales is understandable for many practical reasons, arguably the most important lesson of the last several decades is the importance to local communities of oceanographic processes operating on much larger scales in time and space. With few exceptions, there are no time-series observations that allow a holistic definition of what is natural for the ocean ecosystem (Dayton, 2003).

Some systems are now almost as well understood as terrestrial systems that have been studied for centuries. Focusing on these systems allows us to make predictions about future condition of ecosystems and trends in populations of organisms, which are in turn needed to develop effective management regimes and bring about necessary policy changes. But making generalizations from a few well-known systems like tropical coral reefs is risky, given the structural and functional diversity that is exhibited by different portions of the oceans and coastal areas. Given that we cannot wait for perfect ecological understanding, however, marine conservationists would be best served by promoting adaptive management wherever possible, so we might learn as we go along. Adaptive management frameworks not only position us for more effective management, but also increase the speed with which critical new knowledge is gained.

Finally, integrated and holistic approaches that tackle the myriad, cumulative threats to marine systems are needed. In order to match the scale of these large, highly interconnected and in many cases open systems, international cooperation may be needed to achieve real conservation.

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Glossary

Allee effect: the relationship between high numbers of reproducing adults and the successful subsequent recruitment of young.

Anadromous: fish that hatch their rear in freshwater, migrate to the ocean to grow and mature, and migrate back to fresh water to spawn.

Anoxic: without oxygen.

Ballast water: water taken up or released by a ship to stabilize it, or to raise/lower it in the water column.

Bathymetry: the measures of the depth of the ocean floor from the water surface; the oceanic equivalent of topography.

Benthos: the bed or bottom of a body of water, including the layers of much silt, or sand.

Biofouling: the formation of bacterial film (biofilm) on fragile reverse osmosis membrane surfaces.

Biome: an entire community of living organisms in a single major ecological area.

Biota: the animals, plants, and microbes that live in a particular location or region.

Cnidarian: a coelenterate. Radially symmetrical animals having saclike bodies with only one opening and tentacles with stinging structures. They occur in polyp or medusa forms.

Coalesced: grown together, fused or joined together into a whole.

Coastal zone: lands and waters adjacent to the coast that exert an influence on the uses of the sea and its ecology, or whose uses and ecology are affected by the sea.

Continental shelf: a submerged border of a continent that slopes gradually and extends to a point of steeper descent to the ocean bottom.

Copepods: a common herbivorous zooplankton. Small crustaceans found in either salt or fresh water.

Coriolis force: a force exerted on a parcel of air (or any moving body) due to the rotation of the earth. This force causes a deflection of the body to the right in the Northern hemisphere and to the left in the Southern hemisphere.

Crustacean: aquatic arthropods that are characterized by a segmented body, chitinous exoskeleton, a pair of often modified appendages on each segment, and two pairs of antennae. They include lobsters, shrimps, crabs, wood lice, water fleas, and barnacles.

Ctenophore: any of a phylum (Ctenophora) of marine animals superficially resembling jellyfishes but having biradial symmetry and swimming by means of eight meridional bands of transverse ciliated plates; also called comb jellies.

Dredge: equipment for collecting and bringing up objects from the seabed by dragging.

Echinoderm: a large group of animals characterized by five-fold symmetry and a skeleton of calcite plates. Examples include starfish, urchins, and sea lilies.

Ecological footprint: a calculation that estimates the area of Earth's productive land and water required to supply the resources that an individual or group demands, as well as to absorb the wastes that the individual or group produces.

Ecosystem engineer: any organism that creates or modifies habitats.

Estuary: the wide part of a river where it nears the sea, and fresh and salt water mix.

Eutrophication: over-enrichment of a water body with nutrients, resulting in excessive growth of organisms and the depletion of the oxygen concentration.

Extirpation: the elimination of a species or subspecies from a particular area, but not from its entire range.

Fecund: species that have a high reproductive output based on when and how often they reproduce.

Fiord: an estuary that occurs in a deep, narrow, drowned valley, originally formed by glaciers.

Flocculent layer: having a fluffy character or appearance.

Foraminifera: a class of animals of very low organization and generally of small size, having a jelly-like body, a surface from which delicate filaments can be given off and retracted for the prehension of external objects, and having a calcareous or sandy shell, usually divided into chamber and perforated with small apertures.

Global commons: natural assets outside national jurisdiction such as the ocean, outer space, and the Antarctic.

Gyres: currents moving in large circles in the Northern and Southern hemispheres.

Intertidal: the zone between high and low tide.

Keystone species: a species that plays a large or critical role in supporting the integrity of its ecological community, and whose removal leads to a series of extinctions within the ecosystem.

Lagoon: a body of comparatively shallow salt water separated from the deeper sea by a shallow or exposed sandbank, coral reef, or similar feature.

Longshore current: current located in the surf zone and running parallel to the shore as a result of waves breaking at angle on the shore.

Mangrove forest: an expanse of mangrove trees. Trees that live along the shore in tropical waters with their roots in the salt water.

Marine protected area: an area of 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.

Marine snow: aggregates of detritus, visible to the naked eye, that consists of dead organisms, discarded feeding structures, fecal pellets, and other organic debris.

Marsh: a low-lying wetland with grassy vegetation, usually a transition zone between land and water.

Maximum sustainable yield: the largest average catch that can be taken continuously (sustained) from a stock under existing environmental conditions.

Meso-scale: the scale of meteorological phenomena that ranges in size from a few kilometers to 200 kilometers in horizontal extent, includes local winds, thunderstorms, and tornadoes.

Mollusk: an invertebrate animal with soft, unsegmented bodies, such as clams and snails, usually enclosed in a calcium shell.

Pelagic: fish and animals that live in the open sea, away from the sea bottom.

Photic zone: the layer of the ocean that is penetrated by sunlight, extending to a depth of about 200 meters.

Phyletic diversity: of or relating to the diversity of the evolutionary development of organisms.

Phytoplankton: Microscopic floating plants, mainly algae that live suspended in bodies of water and that drift about because they cannot move by themselves or because they are too small or too weak to swim effectively against a current.

Propagule: any part of a plant that can give rise to a new individual and aids in the dispersal of the species.

Protist: a heterogeneous group of living things, comprising those eukaryotes that are neither animals, plants, or fungi, or unicellular, or colonial organisms. Includes most protozoa and most algae.

Refugia: an area, untreated with pesticides, provided to preserve susceptible populations of pests.

Regime shift: a rapid modification of ecosystem organization and dynamices with prolonged consequences.

Riparian: relating to or living or located on the bank of a natural watercourse (as a river) or sometimes of a lake or tidewater.

Seiches: the oscillation of a body of water at its natural period. Coastal measurements of sea level often show seiches with amplitudes of a few centimeters and periods of a few minutes due to oscillations of the local harbor, estuary, or bay, superimposed on the normal tidal changes.

Spawn: the act of reproduction of fishes.

Sponge: a poriferan. Primitive, sessile, mostly marine, water dwelling filter feeders that pump water through their matrix to filter out particulates of food matter.

Stratification: the division into distinct layers (or strata).

Thermocline: a vertical negative teperature gradient in some layer of a body of water that is appreciably greater than the gradients above and below this level.

Thermohaline: the circulation path determined by temperature and salt, downwellings due to surface-water density created by low temperature and high salinity.

Trawl: a string of traps or nets connected by a line with two buoys marking each end that are dragged along the bottom to catch fish or towed at various depths above the bottom for the same purpose.

Upwelling: vertical currents that deliver cold, nutrient-rich bottom waters to the surface.

Zooplankton: small, usually microscopic animals (such as protozoans) that drift with the currents. May be either herbivores or carnivores.

Assessing Threats in Conservation Planning and Management

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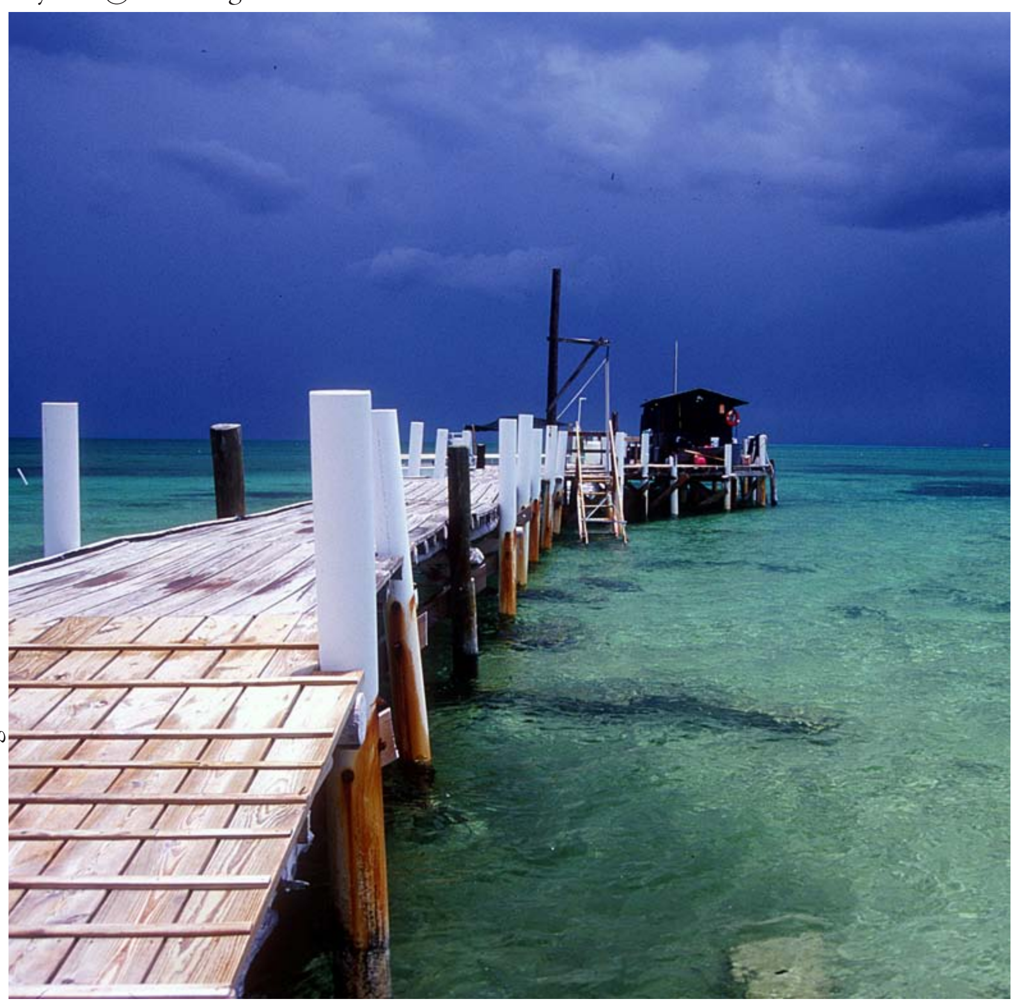

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Assessing Threats in Conservation Planning and Management

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Conceptual Roadmap of the Synthesis and Relationship to Other NCEP Modules

This synthesis reviews the role of threat assessment in conservation planning and management in setting conservation targets (what targets to conserve?), identifying priority strategies (how to conserve?), and determining their effectiveness (are strategies effective?).

The first part of the synthesis includes an overview of the use of threat assessment in **conservation planning** (what and how to conserve) by focusing on two broad aspects: (1) species-level, and (2) global-, regional-, and local(site)-level priority setting.

The section on species-level priority setting briefly discusses the IUCN Red List Programme, BirdLife International's Important Bird Areas (IBAs) Programme, Key Biodiversity Areas, and range-level priority setting for individual species (e.g., Jaguar Conservation Units, Tiger Conservation Units). The four approaches use threats as one of many criteria to prioritize species or their habitats.

The section on global-scale priority setting discusses the use of threat assessment in four approaches that identify the entire planet as the planning universe, and then attempt to identify places that require conservation attention: Hot Spots, Last Wild Places, Global 200, and Frontier Forests. Following this, the synthesis reviews the use of threat assessment in regional-scale priority-setting approaches such as The Nature Conservancy's seven-step planning framework and World Wildlife Fund's Ecoregion Based Conservation which involve selecting one or a cluster of ecologically defined regions as the planning universe and establishing a set of geographic priorities and strategies within them. In local-scale priority setting, the role of threat assessment is to identify and rank threats to conservation targets in order to select appropriate conservation strategies. The synthesis reviews two planning tools used in site conservation: conceptual models and The Nature Conservancy's Conservation Action Planning approach.

The second part of the synthesis reviews the role of threat assessment in measuring **management effectiveness** with reference to monitoring approaches that fall into two broad categories: (1) the assessment of the status and impacts of threats, and (2) the measurement of ecological integrity of conservation targets.

This section concludes with a comparison of threat monitoring methodologies focusing on two approaches: Threat Reduction Assessment and Rapid Assessment and Prioritization of Protected Area Management.

This overview is closely linked yet significantly different in focus from two other related modules, *An Overview of Threats to Biodiversity* and *Monitoring for Adaptive Management in Conservation Biology. An Overview of Threats* provides a discussion on the various direct threats to biodiversity such as habitat fragmentation, invasive species, pollution, overexploitation, and global climate change. There is a detailed description of each category of threat and ecological impacts on biodiversity and processes sustaining biodiversity.

Monitoring for Adaptive Management in Conservation Biology provides essential concepts for designing successful monitoring projects that directly serve conservation efforts through adaptive management. According to Margoluis and Salafsky (1998), all three parts of any conservation project can be monitored: the state of the target condition (species, ecosystems, protected areas, etc.), the success in mitigating threats to the target condition, and the process of implementing interventions. The module primarily focuses on monitoring the state of the target condition, which could be a particular species, a suite of species, a protected area, an ecosystem type, or a landscape comprising all of these components. Specifically, it describes (1) how to articulate clear management goals, (2) how to convert these into explicit monitoring goals, (3) how to estimate sampling necessary to meet those monitoring goals, (4) how to analyze monitoring data to determine if change has occurred, and (5) how to report results to stakeholders in a timely and effective fashion.

Introduction

Conservation strategies designed and implemented by practitioners to protect species, landscapes, and ecosystems are largely in response to *threats* to *biodiversity*. Hence, threat assessment involving the identification, evaluation, and ranking of threats to specific conservation targets is an integral part of conservation planning and management. Given the urgency for conservation action within the context of limited financial resources and a growing recognition of the deepening biodiversity crisis, the emphasis on systematic conservation planning and evaluation of management effectiveness has greatly increased in recent years. Government and non-government conservation organizations are under increasing pressure to pay more attention to three broad questions:

1. What targets should be conserved?
2. How should conservation strategies be designed?
3. Are conservation strategies effective in achieving conservation goals?

Threat assessment is critical to addressing all three questions.

What Targets Should be Conserved?

Threat assessment is a significant component of conservation priority setting processes for species and ecosystems (Dinerstein et al., 2000; Hilton-Taylor, 2000; Groves et al., 2002; IUCN, 2002). For example, regional conservation planning may identify several hundred potential conservation areas within a planning region on the basis of ecological criteria alone such as diversity, *endemism*, uniqueness, or the value of ecological services. Some areas, however, are in more urgent need of action than other areas. Therefore, a further step in the conservation planning process prior to implementation is to set priorities for action within the planning region. Threat assessment is an important criterion used to set such priorities.

How Should Conservation Strategies be Designed?

Once sites have been selected, threat assessment can help design strategies to conserve biodiversity targets (Margoluis and Salafsky, 1998). There is a growing trend among conservation practitioners to design conservation projects by identifying threats to conservation targets (such as species and ecosystems) at a site and then developing interventions or strategies that explicitly address these threats (e.g., Bryant et al., 1997; Salafsky and Margoluis, 1999; TNC, 2005).

Are Conservation Strategies Effective in Achieving Conservation Goals?

Conservation practitioners are increasingly asked to measure the effectiveness of their efforts to conserve biodiversity in ways that are scientifically sound, practical, and comparable across sites. One way to assess effectiveness of management action is to monitor threats to conservation targets; for example, are the most critical threats that affect biological diversity at a park changing in their severity or geographic extent as a result of conservation strategies (or lack thereof)? Or, has poaching declined as a result of efforts to develop and improve domestic livestock practices as a protein source for local communities? Threat assessment methodologies can be used in monitoring protocols to measure the effectiveness of management action (Salafsky and Margoluis, 1999; Hockings et al., 2000; Margoluis and Salafsky, 2001).

Threat assessment is also used to set priorities in conservation planning of marine areas (Salm et al., 2000); however, this module will emphasize the role of threat assessment in terrestrial conservation planning and management.

Assessing Threats in Conservation Planning

Priority Setting at the Species-level

The following section provides a brief overview of four approaches to assessing threats at the species level. These approaches use threats as one of several criteria to prioritize species or their habitats:

1. The IUCN Red List Programme evaluates the status of species relative to other species in terms of a species' *extinction* risk and allows for monitoring.
2. The Important Bird Areas Programme identifies critical sites for birds.
3. The Key Biodiversity Area approach identifies, documents, and protects networks of sites critical for the conservation of global biodiversity.
4. Range-wide priority setting approaches use threat assessment to set conservation priorities for individual species (for example, Tiger Conservation Units and Jaguar Conservation Units).

1. The IUCN Red List Programme
The IUCN (International Union for the Conservation of Nature and Natural Resources and also known as the World Conservation Union) Red List is a tool to help assess and monitor the status of biodiversity at the species level (www.redlist.org). Threatened species lists such as the Red List provide a qualitative estimate of the risk of extinction.

The goals of the IUCN Red List Programme are to: (a) provide a global index of the state of degeneration of biodiversity, and (b) identify and document those species most in need of conservation attention if global extinction rates are to be reduced (Hilton-Taylor, 2000). The listing process utilizes a comprehensive system of threat classification and criteria to place species in one of seven broad categories: "extinct in the wild," "critically endangered," "endangered," "vulnerable," "lower risk," "data deficient," and "not evaluated" (Hilton-Taylor, 2000; IUCN, 2002; Baillie et al., 2004). For example, the 2004 IUCN Red List contains 15,589 species threatened with extinction. The assessment includes species from a broad range of taxonomic groups including vertebrates, invertebrates, plants, and fungi.

According to Possingham et al. (2002), there are four common ways threatened species lists are used: (1) to set priorities for resource allocation for species recovery, (2) to inform reserve system design, (3) to constrain development and exploitation, and (4) to report on the state of the environment. Possingham et al. (2002) acknowledge that such lists fulfill important political, social, and scientific needs, and are frequently the only tools based on sound ecological knowledge available for decision-making. However, they warn that the lists were not *designed* for any of the four purposes outlined above and provide a useful summary of their limitations.

BirdLife International, an international NGO (non-governmental organization), has been analyzing and documenting the status of the world's threatened bird species since the 1970s, and is the official Listing Authority for birds for the IUCN Red List. BirdLife collates information on threatened birds from a global network of experts and from published and unpublished sources. This information is used to assess each species' IUCN Red List category (and hence extinction risk) using standard quantitative criteria based on *population* size, population trends, and range size (Stattersfield and Capper, 2000).

2. The Important Bird Areas (IBA) Programme
The information generated by the Red List Programme outlined above is also used to focus global conservation efforts and to guide BirdLife's priorities for action. For example, BirdLife International's Important Bird Areas (IBA) Programme is a worldwide initiative aimed at identifying, documenting, and protecting a network of critical sites for birds. IBAs are key sites for conservation - small enough to be conserved in their entirety and often already part of a protected-area network. They fulfill one (or more) of the following criteria:

- Hold significant numbers of one or more globally threat-

ened species
- Are one of a set of sites that together hold a suite of restricted-range species or biome-restricted species
- Have exceptionally large numbers of migratory or congregatory species

3. The Key Biodiversity Area Approach
The goal of the Key Biodiversity Area approach is to identify, document, and protect networks of sites that are critical for the conservation of global biodiversity (Eken et al., 2004). This methodology builds up from the identification of species conservation targets (through the IUCN Red List) and nests within larger-scale conservation approaches (such as IBAs). Sites are selected using standardized, globally applicable, threshold-based criteria, driven by the distribution and population of species that require site-level conservation. Such species fall into two main and non-exclusive classes: species that are threatened or species that are geographically concentrated. Thus, the criteria address the two key issues for setting site conservation priorities: vulnerability and irreplaceability.

Key Biodiversity Area criteria cover:

- Globally threatened species that have been assessed following the IUCN Red List criteria as having a high risk of extinction
- Restricted-range species with small global distributions
- Assemblages of species confined to a particular broad habitat type, or biome
- Congregations of species that gather in large numbers at specific sites during some stage in their life cycle

4. Range-level priority setting for individual species
Threat assessment is also used to set conservation priorities over the entire *range* for individual species, such as tigers and jaguars (Dinerstein et al., 1997; Sanderson et al., 2002a). For example, a framework to identify high priority areas and actions to conserve tigers in the wild uses scoring indices for threats to tigers, such as habitat degradation and poaching, to prioritize Tiger Conservation Units, which are defined as "blocks of existing habitats that contain, or have the potential to contain, interacting populations of tigers" (Dinerstein et al., 1997). Similarly, the Wildlife Conservation Society's range-wide priority setting for jaguars identified and prioritized Jaguar Conservation Units (JCUs) as having high, medium, or low probability of long-term survival of the population using a weighted scoring system that included criteria such as JCU size, connectivity, habitat quality, hunting of jaguars, hunting of jaguar prey, and jaguar population status (Sanderson et al., 2002a). Such range-wide priority setting approaches can potentially be applied to other taxa as well.


Snakes sold for medicinal use in Vietnam (Source: K. Frey)

Table 1 presents a comparison of these approaches. The three approaches share a common objective of using threats as one of many criteria to prioritize species (Red List, BirdLife's threatened species) or their habitats (Important Bird Areas, Key Biodiversity Areas, Tiger Conservation Units, Jaguar Conservation Units).

Priority Setting at Global, Regional, and Local (Site) Scales

Planning methods and conservation strategies of governmental and non-governmental organizations are increasingly focusing on large spatial areas or regions inhabited by many species and natural communities. Threat assessment forms

Table 1: Priority setting at the species-level						
	Organization	**Scale**	**Prioritized Categories**	**Criteria for classification**	**Method**	**Reference**
IUCN Red List	IUCN Red List Programme	Species	Extinct Extinct in the wild Critically endangered Endangered Vulnerable Lower risk (Conservation Dependent, near threatened, least concern)	Several (see pages 54 and 55 in Hilton-Taylor, 2000)	Quantitative	Hilton-Taylor, 2000; www.redlist.org
BirdLife's Important Bird Areas (IBAs)	BirdLife International	Species and their habitats	Important Bird Areas	(i) Sites with significant numbers of one or more globally threatened species (ii) Sites with a suite of restricted-range species or biome-restricted species (iii) Sites with exceptionally large numbers of migratory or congregatory species	Semi-quantitative	www.birdlife.net
Key Biodiversity Areas	Birdlife International Conservation International Plantlife International	Networks of sites	Key biodiversity areas	Sites with (i) globally threatened species (ii) restricted-range species (iii) assemblages of species restricted to a particular broad habitat type or biome (iv) congregations of species that gather in large numbers at specific sites during some stage in their life cycle	Semi-quantitative	Eken et al., 2004
Tiger Conservation Units (TCUs)	World Wildlife Fund/Wildlife Conservation Society	Landscape [TCUs nested by tiger habitat types]	Level I Level II Level III Immediate Surveys	Habitat integrity Poaching pressure Population status	Qualitative (Weighted scoring)	Dinerstein et al., 1997
Jaguar Conservation Units (JCUs)	Wildlife Conservation Society	Landscape	High, medium, low probability of long-term survival Jaguars extirpated Status unknown	JCU size Connectivity Habitat quality Hunting of Jaguars Hunting of prey Jaguar population status	Qualitative (Weighted scoring)	Sanderson et al., 2002a

Table 2: Assessing threats in global, regional, and site-level conservation planning

Title	Organization	Scale	Role of threat assessment	Variables used to measure threat	Reference
Global 200 ecoregions	WWF	Global	What to conserve?	Total habitat loss	Dinerstein et al., 1995
				Degree of fragmentation	Olsen and Dinerstein, 1998
				Water quality	
				Estimates of future threat	
Hotspots	CI	Global	What to conserve?	Habitat loss (70% or more of primary vegetation lost)	Myers et al., 2000
WRI Frontier Forests	WRI	Global	What to conserve?	Commercial logging	Bryant et al., 1997
				Other biomass harvest (removal of fuelwood and construction materials, grazing)	
				Forest clearing (for agriculture, residential housing, etc.)	
				Road construction and other infrastructure development (e.g. powerlines, pipelines)	
WCS's Last Wild Places	WCS	Global	What to conserve?	Human Influence Index	Sanderson et al., 2002b
				Population density	
				Land transformation	
				Accessibility	
				Power infrastructure	
TNC's Ecoregional Planning Approach	TNC	Regional	How to conserve? (To set priorities for action)	Severity, Scope, Contribution, Irreversibility)	Groves et al. 2002
WWF's Ecoregional Planning Approach	WWF	Regional	How to conserve? (To set priorities for action)	Conversion	Olsen et al., 2001
				Degradation	
				Wildlife exploitation	
TNC Conservation Action Planning Process	TNC	Local	How to conserve? (To set priorities for action)	Severity of damage	TNC, 2005
				Scope of damage	
				Contribution	
				Irreversibility	
FOS TRA		Local	How to conserve? (To set priorities for action)	Area	Salafsky and Margoluis, 1999
				Intensity	
			Are actions working?	Urgency	
WWF (RAPPAM Framework)	WWF	Local	How to conserve? (To set priorities for action)	Extent	Ervin, 2003b
				Impact	
				Permanence	
			Are actions working?	Probability	
				Trend over time	

an important component of conservation planning methods helping to prioritize sites within large, terrestrial spatial areas (Groves et al., 2002). There are three "simplified" planning scales typically considered by conservation planners: global, regional, or local (Table 2).

1. Global-Scale Priority Setting

Global-scale conservation priority setting exercises are numerous and include World Wildlife Fund's Global 200 *Ecoregions* (Olson and Dinerstein, 1998), Conservation International's Biodiversity *Hotspots* (Myers et al., 2000), Birdlife International's Important Bird Areas (Grimmett and Jones, 1989), World Resources Institute's *Frontier Forests* (Bryant et al., 1997), and the Wildlife Conservation Society's *Last Wild Places* (Sanderson et al., 2002b). These analyses identify the entire planet as the planning universe, and then attempt to identify all the places (usually large regions or ecoregions) that require increased conservation attention. The priority areas identified in these global prioritization schemes are invariably large (e.g., the Caribbean, or the Tropical Andes) but sometimes include smaller areas (e.g., Important Bird Areas).

The criteria for determining priority areas for conservation are many and varied, but almost always include threat assessment at some point (Table 2). Two of the four approaches (Hotspots, Last Wild Places) use threats as the "primary factor" to define the priority regions, and two other approaches (Global 200, Frontier Forests) use threats secondarily to identify priority regions.

Conservation International's Hotspots are defined on the basis of habitat loss (>70% of primary vegetation lost) and endemism (Myers et al., 2000; Myers, 2003). The Wildlife Conservation Society's Last Wild Places are identified using threat proxies (population density, accessibility, power infrastructure, and land transformation) for human influence (Sanderson et al., 2002b).

The Global 200 initiative of the World Wildlife Fund (WWF) defines "ecoregions" as relatively large units of land containing a distinct assemblage of natural communities and species with boundaries that approximate the original extent of natural communities prior to major land-use change. The Global 200 Ecoregions are considered by WWF to be the richest, rarest, and most distinctive examples of all the Earth's diverse natural habitats.

The Global 200 uses threats at a secondary level to prioritize conservation actions within ecoregions that are identified on the basis of purely ecological and *biogeographical* criteria. Conservation assessments of the Global 200 Ecoregions are based on features such as total habitat loss, the degree of *fragmentation*, water quality, and estimates of future threat. The different ecoregions are classified into one of three broad categories: critical/endangered, vulnerable, or relatively stable/relatively intact (for a more detailed discussion of scoring ecoregions for conservation status, see Dinerstein et al., 1995; Ricketts et al.,1999; Wikramanayake et al., 2002).

Similar to the Global 200 approach, World Resources Institute's approach defines Frontier Forests as large, ecologically intact, and relatively undisturbed natural forests of the world and uses threat criteria to classify frontier forests secondarily as "threatened" or "low-threat" potentially vulnerable forests (Bryant et al., 1997).

2. Regional-Scale Priority Setting

Regional planning scales are intermediate between "coarse" global planning scales and the "fine" local scales typically associated with single site planning. Regional scale conservation planning often involves selecting one or a cluster of ecologically defined regions as the planning universe, and establishing a set of geographic priorities and strategies within them (Olson et al., 2001). Threat assessment is a useful tool for setting priorities for action among conservation areas within a region.

The Nature Conservancy's ecoregional planning process outlines a framework for developing regional plans to conserve biological diversity (TNC 2000a; 2003b; Groves et al., 2002). The ultimate objective in the planning framework is to set priorities for action among the portfolio of potential conservation areas. The framework uses five criteria for setting these priorities: degree of existing protection, conservation value, threat, feasibility, and leverage. The most important criterion among these is the degree of threat to conservation areas and to the targets contained in them. Evaluating threats is important for two reasons: (1) the severity and scope of threats help determine which conservation areas are in need of urgent conservation action, and (2) for threats that recur across many conservation areas, it may be possible to design multi-area strategies to abate these threats (Groves, 2003). Conservation areas that face critical threats are assigned a higher priority than those that are not imperiled - in other words, the greater the degree of threat, the higher the priority.

Logging in Vietnam (Source: C. Snyder)

In parallel, WWF's ecoregional planning process is a strategy for conservation planning and action at a scale that is determined by the patterns of biological diversity and the ecological processes that sustain them (Olson et al., 2001). The process focuses on maintaining these patterns and processes over the long term. A hypothesis of the Eco-Regional Based Conservation (ERBC) process is that addressing threats that occur over large spatial scales is a more cost-effective approach than addressing threats on a site-by-site basis. Hence the framework involves a threat assessment of priority areas, which is intended to gauge the urgency of conservation action and also to help determine the kinds of interventions that may be needed. Threats are categorized into three broad classes: conversion of ecosystems, degradation of ecosystems, and wildlife exploitation. Weighted scoring is used to identify high, medium, and low levels of threat.

The role of threat assessment in both regional planning exercises described above is similar: to identify conservation strategies and to gauge urgency of action.

3. Local (Site-Level) Priority Setting

In contrast to global and regional scales, conservation planning at local scales involves less of a focus on priority setting and more attention to specific site conservation strategies. At global and regional scales, the driving question is frequently where to work, and the process involves selecting candidate areas (where to conserve). At local scales, the decision has already been made to work at a particular site or area, and the driving question becomes how to protect the biodiversity contained in that site; site management issues replace site selection concerns. For conservation areas at typical, local site scales (e.g., protected areas, conservation reserves, etc.), it is extremely important to know the nature and status of biodiversity *plus* the distribution, severity, and intensity of threats impacting the sites.

In general, the role of threat assessment for site conservation planning is to identify and rank threats to conservation targets in order to select appropriate conservation strategies. There are a variety of different approaches to characterizing threats to conservation targets such as protected areas, conservation reserves, etc. The simplest and most common approach is a textual description of the threats to a particular conservation target. While this method identifies threats, it generally does not adequately characterize them for conservation planning purposes. In contrast, a formal assessment measures the relative importance of threats affecting a particular conservation target and thereby informs the most effective selection of conservation strategies (Sayre et al., 2000).

Site Conservation Planning Tools

Conceptual models

Margoluis and Salafsky (1998) have developed the conceptual model approach to designing, managing, and monitoring conservation projects. A conceptual model is a simple, graphic tool to help identify threats affecting biodiversity at a designated site and the conservation actions needed to address those threats. It is viewed as the foundation of all project design, management, and monitoring activities (Margoluis and Salafsky, 1998). The theoretical roots of the conceptual model approach are in diverse fields such as the social sciences, business management, professional practice, and ecosystem management, and are reviewed in Salafsky et al. (2000).

A conceptual model of a conservation project comprises three main components (Margoluis and Salafsky, 1998; see Figure 1):

1. The conservation target, i.e., target condition (such as biodiversity within a protected area) that the project ultimately would like to influence. In most projects, this biodiversity is defined spatially as the species and ecosystems at a specific site, the scale of which can range from a small area to an entire continent. For some projects, however, the targeted biodiversity cannot be tied to specific sites, but must be regarded as a stand-alone entity (e.g., populations of migratory birds or pelagic fish).
2. Causal chains of direct and indirect threats affecting the conservation target. Direct threats are factors that immediately affect the target condition or physically cause its destruction and include habitat fragmentation, *invasive species*, pollution, overexploitation, and global climate change. Indirect threats are defined as factors that underlie or lead to the direct threats. Often referred to as underlying causes of biodiversity loss, indirect threats are complex and stem from many interrelated factors, including population growth, migration, poverty and inequality,

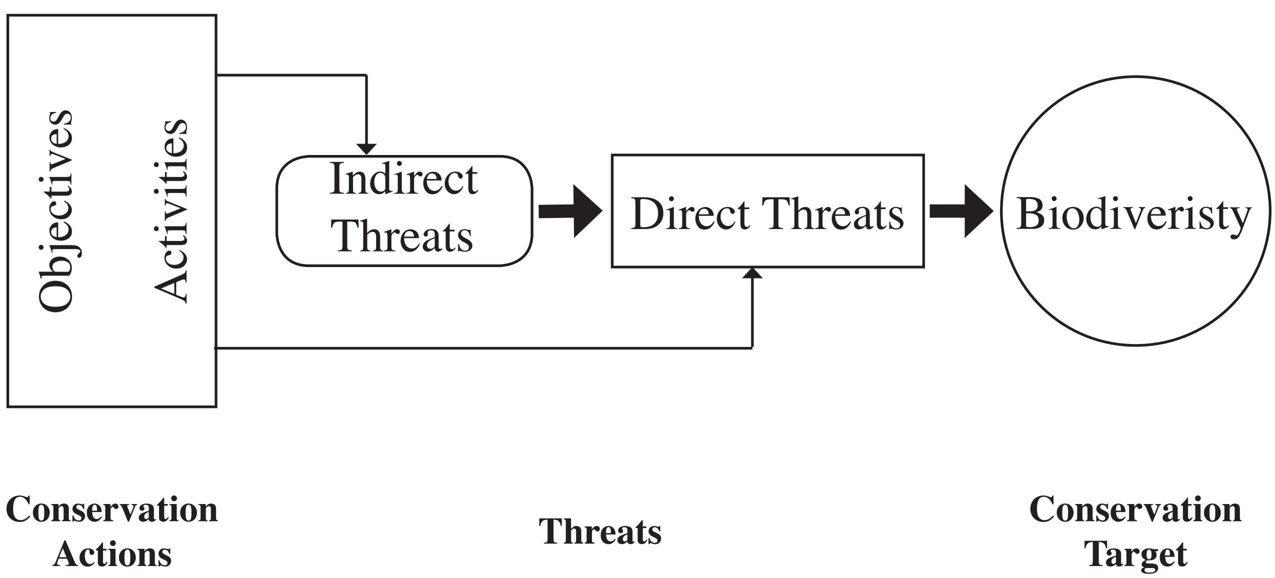

Figure 1: The three main components of a conceptual model of a conservation project include a conservation target, threats (direct and indirect), and conservation actions (Margoluis and Salafsky, 1998)

civil unrest, weak institutions and governance structures, weak legislation and lack of enforcement, and market forces and failures.

3. The third part of the model is a description of the conservation actions (objectives and activities) that project managers can use to counter the threats to their conservation target. A detailed description of the steps involved in building conceptual models of projects is provided in Margoluis and Salafsky (1998).

Once the conservation project has identified the direct and indirect threats influencing the focal conservation target, the next step is to assess the relative importance of these threats. An assessment of threats helps determine which threats need to be addressed or modified to have some impact on the status of the conservation target (Margoluis and Salafsky, 1998; Salafsky and Margoluis, 1999). Threats are ranked on the basis of three criteria: area, intensity, and urgency (see below).

TNC's Conservation Action Planning (CAP) (TNC, 2005)

The Nature Conservancy has developed a method known as the Conservation Action Planning process that includes developing *strategies*, taking action, and measuring success at any scale including at the site level. The system is based on the earlier 5-S Framework for site conservation. The five S's include:

- *Systems:* the biodiversity targets occurring at a site, and the natural processes that maintain them, that will be the focus of planning
- *Stresses:* the types of degradation and impairment afflicting key attributes of the system(s)
- *Sources:* the agents generating the stresses
- *Strategies:* the types of conservation actions deployed to abate sources of stress (threat abatement) and altered attributes of the systems (restoration)
- *Success:* measures of system viability and threat abatement

The conservation approach is based on the principle that stresses must be abated to ensure viable conservation targets. The approach develops and implements conservation strategies to (1) abate the critical sources of stress (i.e., threat abatement), and (2) directly reduce persistent stresses (i.e., restoration).

The Conservation Action Planning process involves the following 4 stages and a total of 10 steps:

A. Defining the project
B. Developing conservation strategies and measures
C. Implementing conservation strategies and measures
D. Using results to adapt and improve

The following is a brief description of the activities under each stage:

A. Defining the project.
Step 1. Identify people involved in the project with the selection of project leader, team members and assignment of roles.

Step 2. Define project scope and focal conservation targets with a brief text description and basic map of project area or scope, a statement of the overall vision of the project and a selection of no more than 8 focal conservation targets and explanations of why they were chosen.

B. Developing conservation strategies and measures.
Step 3. Assess *viability* of focal conservation targets including (i) the selection of at least one key ecological attribute and measurable *indicator* for each focal target, (ii) assumptions regarding acceptable range of variation for each attribute, (iii) determination of current and desired status of each attribute and (iv) brief documentation of viability assessments and any potential research needs.

Step 4. Identify critical threats including the identification and rating of stresses and sources of stress for each focal target.

Step 5. Conduct Situation Analysis. This includes indirect threats/opportunities and associated stakeholders behind all critical threats and degraded attributes and a picture in narrative form or a simple diagram of hypothesized linkages between indirect threats and opportunities, critical threats and focal targets.

Step 6. Develop strategies: objectives and actions. This includes identifying good *objectives* for all critical threats and degraded *key ecological attributes* that the project is taking action to address and one or more strategic actions for each conservation objective.

Step 7. Establish measures. This includes a list of indicators and methods to track the effectiveness of each conservation action.

C. Implementing conservation strategies and measures.
Step. 8. Develop work plans. This involves developing lists of major action steps and monitoring tasks, assignments of steps and tasks to specific individuals, timeline, brief summary of *project capacity* and a rough project budget.

Step 9. Implementation through actions and measures.

D. Using results to adapt and improve.
Step 10. Analyze, learn, adapt, and share. This step involves appropriate and scheduled analyses of data, updated viability and threat assessments, modification to objectives, strategic actions and work plans as warranted, updates of project documents and identification of key audiences and appropriate communication products.

In Step 4, the process identifies four variables used to measure threats:

- *Scope of Damage* is "the geographic scope of impact to the conservation target expected within 10 years under current circumstances."
- *Severity of Damage* is "the level of damage to the conservation target over at least some portion of the target occurrence that can reasonably be expected within 10 years under current circumstances."
- *Contribution* is "the contribution of a source, acting alone, to the full expression of a stress."
- *Irreversibility* is "the level of reversibility of the stress caused by a source of stress." Each threat is scored for each variable using a 1-4 ranking and the variables are combined through a series of rules to give an overall score for each threat (TNC, 2000b).

The TNC approach sometimes includes a comprehensive situation analysis of local economic, political, and social conditions and stakeholder interests as part of the 5-S planning approach. A situation analysis involves developing an understanding of the various factors that can affect the project's focal conservation targets. The process helps identify and prioritize direct threats; outlines underlying causes; and links targets, threats, and underlying factors in a chain-of-causation and/or conceptual model.

Box 1 provides an example of how TNC used this approach to develop conservation strategies for the Yunnan Great Rivers Project in China.

Evaluating Management Effectiveness Using Threat Assessment

Increasingly, donors and policy makers alike are questioning investment in biodiversity conservation with the overall concern: are conservation projects succeeding? Accordingly, measuring effectiveness of conservation strategies and actions has rapidly grown in importance over the past few years. Practitioners and donors are interested in determining whether conservation goals are being achieved and whether conservation strategies are effective in reducing threats to conservation targets. In response, several institutions have developed systems for measuring the effectiveness of management action (e.g., Hockings, 1998, 2003; Courrau, 1999; Dudley et al., 1999; Salafsky and Margoluis, 1999; TNC, 1999, 2003b; Ervin, 2003b).

Approaches in evaluating management effectiveness can be broadly classified into two categories:

Box 1. Local-Scale Conservation Planning: Developing Conservation Strategies for the Yunnan Great Rivers Project (The Nature Conservancy)

The Nature Conservancy uses conservation area planning to develop conservation strategies for the northwest of China's Yunnan Province, one of Earth's richest biodiversity hotspots. In 1998 the Yunnan provincial government invited The Nature Conservancy to help create a conservation and economic development plan for northwest Yunnan. Preparation of the plan, the first major task of the Yunnan Great Rivers Project, was a two-year endeavor involving surveys, research, and feasibility studies by 40 public and private agencies. The plan identifies the area's richest habitats and biggest threats and then proposes ways to abate those threats.

Yunnan Great Rivers Project facts:

Targets: Yunnan golden snub-nosed monkey, snow leopard, evergreen broadleaf forest, rhododendron shrublands, high-elevation spruce-fir forest

Stresses: Poverty, unsustainable agriculture, logging and fuel wood collection, unplanned tourism, unsustainable levels of harvesting and grazing, population growth

Strategies: Establish a system of durable protected areas, promote alternative energy sources, promote ecologically compatible land-use practices, influence land-use planning, build conservation alliances, promote ecotourism

Results: Plan recommending the creation of 3.4 million acres of new nature reserves adopted by the Chinese Government

Source: Modified from http://nature.org

1. Assessment of the status of threats
2. Measurement of the ecological integrity or population status of conservation targets

In the first case, the question addressed is as follows: are the most critical threats that confront biological resources at a park changing in their severity or geographic scope as a result of conservation strategies (or lack thereof)? For example, has wildlife poaching declined as a result of efforts to develop and improve contained domestic animal husbandry as a protein source for local communities?

In the second case, the question becomes: do the ecological systems, communities, and species that are the focus of conservation efforts occur with sufficient size, with appropriately functioning ecological processes, and with sufficiently natural composition, structure, and function to persist over the long term? For example, are populations of mammals and birds declining at a slower rate, or growing, as a result of alternative protein production activities?

The following is a brief analysis of threat monitoring methodologies with greater emphasis on those that fall into the former category (threat status and impacts assessment) as compared to the latter (ecological integrity or target population assessment). A related module (*Monitoring for Adaptive Management in Conservation Biology*) provides a more comprehensive overview of monitoring target populations or ecological systems.

Most threats analyses have focused on the management effectiveness of protected areas (Ervin, 2003a). A number of organizations such as WWF, TNC, World Commission on Protected Areas (WCPA), and the World Bank have been prominent in addressing the issue of measuring management effectiveness through threat monitoring and have developed a number of methodologies. For a comprehensive review of these methodologies, see Hockings (2003), which analyzes 27 management effectiveness systems and documents the basis of each methodology.

Assessing the Status of Threats

Threat monitoring methodologies have been developed specifically to examine the status of threats within the context of assessing management strength and capacity. For example, TNC's Parks in Peril Scorecard (TNC, 1999) assesses the extent to which threats have been identified and/or are being addressed. In other cases, such as the WWF/CATIE methodology (Cifuentes et al., 2000), specific threats are identified and an assessment is made of how effectively management is addressing the threat. The Threat Reduction Assessment methodology developed by Salafsky and Margoluis (1999), described in detail in the Exercise that accompanies this module (page 115), monitors the threats themselves as a proxy measurement of conservation success. Assessing the degree to which threats have been reduced provides a framework for measuring conservation success. The WWF Rapid Assessment methodology (Ervin, 2003b), also described below (Box 2), uses a more detailed assessment of threats to assess vulnerability and assign priorities for intervention across a number of protected areas. Other methodologies allow the measurement and ranking of threats and pressures either at the protected area system level (Singh, 1999; Ervin, 2003c) or at the site level (Margoluis and Salafsky, 1998; TNC, 2000b).

In practice, threat assessments used to gauge protected area effectiveness are applied at varying scales. While some assessments study the prevalence of threats within a single protected area system (Parks Canada, 2000; Rao et al., 2002), others have been used for a regional sampling of protected areas (Brandon et al., 1998; Carey et al., 2000). The Nature Conservancy has developed a method to monitor threats at ecoregional scales and advocates that threat assessment at such scales is critically important as early warning measures for changes in biodiversity status (TNC, 2003c).

Measurement of Ecological Integrity

However important, measuring threat status is insufficient on its own for several reasons (Parrish et al., 2003). Most significantly, a focus on threat status alone must assume that there is a clear, often linear, relationship between a threat and the status of biodiversity. This runs counter to recent evidence of the nonlinear dynamics of ecosystems and threshold effects (e.g., Scheffer et al., 2001). Overall, measurement of threat status can be considered to be one tool to measure effectiveness, and needs to be accompanied by measurements of ecological integrity of conservation targets (see the *Monitoring for Adaptive Management in Conservation Biology* module). A variety of approaches have therefore been used to measure ecological integrity as an indicator of management effectiveness.

Tracking biodiversity in an area using species census data provides one potential avenue for measuring success; another lies in the use of indices of biotic integrity that incorporate information on both taxonomic and functional composition of sampled communities (e.g. Noss, 1990; Karr and Chu, 1999; Sayre et al., 2000). Such approaches face many challenges in protected areas, especially those that span large areas or incorporate combinations of terrestrial, freshwater, and coastal marine ecosystems (Parrish et al., 2003). The costs of repeated, comprehensive biological censuses can be unsustainable. In addition, biotic responses to threats may lag behind the pace of the threats or be difficult to detect with sparse monitoring data. Further, different biotic measures may be difficult to compare or standardize within the same protected area over time, let alone across multiple protected areas. Different biotic measures may be difficult to interpret for people who are not specialists in the particular taxa involved, and many conservation managers are, in fact, non-specialists (e.g., Salafsky and Margoluis, 1999; Dale and Beyeler, 2001). Finally, threats often change more rapidly and more measurably than systems and species, so measuring threat status provides an "early warning system" to detect changes more quickly than relying solely on measures of ecological integrity (TNC, 2003c).

Box 2. Threat Assessment in the Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) Methodology

The RAPPAM methodology can:

- Identify management strengths and weaknesses
- Analyze the scope, severity, prevalence, and distribution of a variety of threats and pressures
- Identify areas of high ecological and social importance and vulnerability
- Indicate the urgency and conservation priority for individual protected areas
- Help to develop and prioritize appropriate policy interventions and follow-up steps to improve protected area management effectiveness

The methodology includes five steps:

1. Determining the scope of the assessment
2. Assessing existing information for each protected area
3. Administering a Rapid Assessment Questionnaire
4. Analyzing the findings
5. Identifying next steps and recommendations

2 PRESSURES AND THREATS

Pressure:

❍ Has ❍ Has not been a pressure in the last 5 years

In the past 5 years this activity has:	The overall severity of this pressure over the past 5 years has been: Extent	Impact	Permanence
❍ Increased sharply	❍ Throughout (>50%)	❍ Severe	❍ Permanent (>100 years)
❍ Increased slightly	❍ Widespread (15–50%)	❍ High	❍ Long term (20–100 years)
❍ Remained constant	❍ Scattered (5–15%)	❍ Moderate	❍ Medium term (5–20 years)
❍ Decreased slightly	❍ Localized (<5%)	❍ Mild	❍ Short term (<5 years)
❍ Decreased sharply			

Threat:

❍ Will ❍ Will not be a threat in the next 5 years

The probability of the threat occurring is:	The overall severity of this threat over the next 5 years is likely to be: Extent	Impact	Permanence
❍ Very high	❍ Throughout (>50%)	❍ Severe	❍ Permanent (>100 years)
❍ High	❍ Widespread (15–50%)	❍ High	❍ Long term (20–100 years)
❍ Medium	❍ Scattered (5–15%)	❍ Moderate	❍ Medium term (5–20 years)
❍ Low	❍ Localized (<5%)	❍ Mild	❍ Short term (<5 years)
❍ Very low			

For a complete description of the methodology, see Ervin, 2003b. Above is a description of the analysis of the scope, severity, prevalence, and distribution of a variety of threats and pressures (Questionnaire used in STEP 3 of the process).

Pressures are forces, activities, or events that have already had a detrimental impact on the integrity of the protected area (i.e. that have diminished biological diversity, inhibited regenerative capacity, and/or impoverished the area's natural resources). Pressures include both legal and illegal activities, and may result from direct and indirect impacts of an activity. Threats are potential or impending pressures in which a detrimental impact is likely to occur or continue to occur in the future.

Trends over Time

Increases and decreases may include changes in the extent, impact, and permanence of an activity.

Extent

Extent is the range across which the impact of the activity occurs. The extent of an activity should be assessed in relation to its possible occurrence. For example, the extent of fishing would be measured relative to the total fishable waterways. The extent of poaching would be measured relative to the possible occurrence of the species population.

Impact

Impact is the degree, either directly or indirectly, to which the pressure affects overall protected area resources. Possible effects from motorized vehicle recreation, for example, could include soil erosion and compaction, stream siltation, noise disturbance, plant damage, disruption of breeding and denning sites of key species, fragmentation of critical habitat, introduction of exotic species, and increased access for additional threats, such as poaching.

Permanence

Permanence is the length of time needed for the affected protected area resource to recover with or without human intervention. Recovery is defined as the restoration of ecological structures, functions, and processes to levels that existed prior to the activity's occurrence or existence as a threat.

Source: Modified from Ervin, 2003b

Box 3. Application of the RAPPAM Methodology to Evaluate Management Effectiveness of Four National Parks in Bhutan

Goal of the assessment: To analyze the strengths and weaknesses of the first decade of park management, identify areas for improvement, and establish baseline data for future assessments.

Protected Areas: Jigme Dorji National Park (JDNP), Jigme Singye Wanchuk National Park (JSWNP), Royal Manas National Park (RMNP), Thrumsihingla National Park (TNP).

Methodology:
- Rapid Assessment Questionnaires administered during one or more participatory workshop. Assessment focused more on comparative than on absolute threats and weaknesses.
- Various elements of management effectiveness (e.g., biological importance, planning, inputs, and processes) were scored by having respondents reply to statements such as "the siting of the protected area is consistent with the protected area objectives" with a "yes," "mostly yes," "mostly no," or "no" response.
- Respondents assessed past pressures and future threats within their protected areas.
- The questionnaire measured extent (the range in which the activity occurred), impact (the degree to which pressures affected overall protected area resources), and permanence (the length of time needed for the protected area resource to recover with or without management intervention).
- The degree of each pressure and threat was calculated by multiplying its extent, impact, and permanence, using the numerical values shown below.

	Value			
Indicator	**1**	**2**	**3**	**4**
Extent	Localized	Scattered	Widespread	Throughout
Impact	Mild	Moderate	High	Severe
Longevity	Short-term	Medium-term	Long-term	Permanent

Note: A separate value was assigned to each quality, and the three values were multiplied to calculate the degree of each pressure or threat. A degree of 1 to 3 was considered mild, 4 to 9 moderate, 12 to 24 high, and 27 to 64 severe.

Sources: Modified from Ervin, 2003b; Tsering, 2003

An alternative approach to measuring conservation success that is being pursued by a growing number of organizations involves the use of some form of ecological "scorecard." Such scorecards tabulate and synthesize diverse scientific information about the focal biodiversity of an area into a small number of measurement categories, which are standardized for use across multiple areas and conservation projects. Examples include the frameworks developed by The Nature Conservancy (1999), and Harwell et al. (1999). The Nature Conservancy's scorecard for assessing ecosystem integrity and species viability has four core components or steps: (1) selecting a limited suite of focal biodiversity targets, the conservation of which is intended to serve as a framework for protecting the whole; (2) identifying a limited suite of key ecological attributes for each target, along with specific indicators for each that provide the information for measuring target status; (3) identifying an acceptable range of variation for each key ecological attribute of the focal conservation targets, defining the limits of variation within which the key ecological attribute must lie for the target to be considered conserved; and (4) assessing the current status of each target, based on the status of its key ecological attributes with respect to their acceptable ranges of variation, and integrating the assessments of target status into a measure of the status of biodiversity overall (see Parrish et al., 2003). A further category of threat assessment focuses on measuring the impacts of threats on biodiversity targets and is more detailed and quantitative than the assessments described above. Studies have measured land-use changes as indicators of intactness of protected areas (Bruner et al., 2001; Jepson et al., 2002). It is also possible to measure the effects of specific threats such as pollutants affecting water quality (Whittier et al., 2002) or ecotourism visitor impacts in protected areas (Farrell and Marion, 2001). Another approach to monitoring threats is to monitor species persistence within individual protected areas (Revilla et al., 2001; Struhsaker, 2002). Table 3 provides a brief and non-exhaustive listing of the diversity of ecological monitoring approaches used in conservation practice.

Table 3: Threat impact monitoring

Variable monitored	Monitoring parameters	Reference
Land-use change as an indicator of protected area integrity	Land use pressure (land-clearing, logging, hunting, grazing, fire)	Bruner et al., 2001; Jepson et al., 2002
Ecotourism visitor impacts in protected areas	Trails and recreational site impacts	Farrell and Marion, 2001
Species persistence within individual protected areas	Mortality causes (including effects of poaching on mortality) and rates for Eurasian badgers in relation to edge effects	Revilla et al., 2001
Habitat fragmentation	Degree of fragmentation (distribution and intensity); loss of primary forest; structural classification based on radar data	Saatchi et al., 2001
Harvest of plant resources	Effects of harvesting on distribution, abundance, population structure, population dynamics of harvested NTFPs	Hall and Bawa, 1993; Godoy and Bawa, 1993
Impact of hunting and trade on a single species	Type and number of wildlife species captured and traded; offtake	Johnson et al., 2004
Ecological degradation in protected areas	Rate of change in forest cover and habitat (Giant Panda)	Liu et al., 2001

Threat Monitoring in Practice

The following is a brief description of two monitoring frameworks based on threat assessment that are currently being used by conservation practitioners.

Threat Reduction Assessment (Salafsky and Margoluis, 1999)
The threat reduction assessment (TRA) approach described in Salafsky and Margoluis (1999) is used to measure project success and seeks to identify threats not only in order to design projects, but to monitor them as well. In effect, instead of merely monitoring the target condition, the TRA approach monitors the threats themselves as a proxy measurement of conservation success. Assessment of the progress in reducing threats provides a framework for measuring conservation success. Threats are ranked on the basis of three criteria: area, intensity, and urgency. Area refers to the percentage of the habitat(s) in the site that the threat will affect: will it affect all of the habitat(s) at the site or just a small part? Intensity refers to the impact of the threat on a smaller scale: within the overall area, will the threat completely destroy the habitat(s) or will it cause only minor changes? Urgency refers to the immediacy of the threat: will the threat occur tomorrow or in 25 years?

An index known as a "threat reduction index" is used to implement the TRA approach. The index is designed to identify threats, rank them according to their relative importance, assess progress in meeting each of them, and then pool the information to obtain an estimation of actual threat reduction so that meaningful comparisons can be made across different projects.

The TRA method has been used to monitor threats in the Crater Mountain Wildlife Management Area (CMWMA) in the highlands of Papua New Guinea (Box 1); for a butterfly and honey enterprise project in Sulawesi, Indonesia; and for a community-based logging project in the Masoala Peninsula, Madagascar (Biodiversity Conservation Network, 1996; Kremen et al., 1998).

Salafsky and Margoluis (1999) provide a comparison of the TRA method and biological approaches to measuring project success using various theoretical and practical criteria. Advantages of using the TRA approach include greater sensitivity to temporal and spatial changes, ease and cost of data collection, analytical benefits of direct comparisons between different types of projects, and ease in interpreting data. Furthermore, the TRA is viewed as a cost-effective tool for determining whether a given project is achieving its conservation goals or for comparing projects in different ecological and socioeconomic contexts.

Disadvantages of using the TRA approach are related to the fact that it is not a completely direct, precise, unbiased and objective measurement of the state of the biodiversity at a project site. Still, the TRA method has the potential to overcome many of the constraints in implementing biological and impact monitoring methods as described above (Salafsky and Margoluis, 1999).

The Rapid Assessment and Prioritization of Protected Area Management (RAPPAM)

Designed by the World Wildlife Fund, the RAPPAM offers policy makers a tool to develop and prioritize appropriate policy interventions to improve protected area management effectiveness (Ervin, 2003b). In general, the RAPPAM methodology is designed for broad-level comparisons among many protected areas. It can answer a number of important questions: What are the threats facing a number of protected areas and how serious are they? How do protected areas compare with one another in terms of infrastructure and management capacity? What is the urgency for taking action in each protected area? What is the overall level of integrity and degradation of each protected area? How well do national and local policies support the effective management of protected areas? What are the most strategic interventions to improve the entire system? Although it can be applied to a single protected area, the RAPPAM methodology is not designed to provide detailed, site-level adaptive management guidance to protected area managers (see Ervin, 2003b for the complete methodology and its applications).

The RAPPAM methodology helps identify management strengths and weaknesses, and analyzes the scope, severity, prevalence, and distribution of various threats and pressures. Pressures are defined as forces, activities, or events that have already had a detrimental impact on the integrity of the protected area (i.e. that have diminished biological diversity, inhibited regenerative capacity, and/or impoverished the area's natural resources). While pressures include both legal and illegal activities, and may result from direct and indirect impacts of an activity, threats are potential or impending pressures in which a detrimental impact is likely to occur or continue to occur in the future. For example, within a protected area such as the Thrumsingla National Park in Bhutan, ongoing poaching of wildlife for commercial trade constitutes a pressure, whereas road construction, in the form of road widening, constitutes a major future threat (Tsering, 2003).

The primary data collection tool of the RAPPAM methodology is the rapid assessment questionnaire. The questionnaire covers all aspects of the international evaluation framework developed by the World Commission on Protected Areas (WCPA) (Box 3; Hockings, 2003) but emphasizes two major areas: (1) contextual issues, including future threats, past pressures, vulnerability, and biological and socioeconomic importance; and (2) management effectiveness, including a variety

Table 4: Comparison of Threat Assessment Methods			
Organizational approach	**Threat categories**	**Variables used to measure threats**	**Measuring threats**
TNC Conservation Action Planning Process (TNC, 2005)	**Stresses:** Types of degradation and impairment afflicting key attributes of the system(s). **Sources:** Agents generating the stresses.	**Scope:**Geographic scope of impact to the conservation target expected within 10 years under current circumstances. **Severity:** Level of damage to the conservation target over at least some portion of the target occurrence that can reasonably be expected within 10 years under current circumstances. **Contribution:** Contribution of a source, acting alone, to the full expression of a stress. **Irreversibility:** Reversibility of the stress caused by a source of stress.	Threat scored for each variable on 1-4 ranking: Very High, High, Medium, Low
WWF (RAPPAM Framework) (Ervin, 2003b)	**Pressures:** Forces, activities, or events that have already had a detrimental impact on the integrity of the protected area (i.e. that have diminished biological diversity, inhibited regenerative capacity, and/or impoverished the area's natural resources. **Threats:** Potential or impending pressures in which a detrimental impact is likely to occur or continue to occur in the future.	**Extent:** Range in which the activity occurs- in relation to its possible occurances. **Impact:** Degree. either directly or indirectly, to which the threat affects overall protected area resources. **Permanence:** Length of time needed for the affected protected area resource to recover with or without human intervention. **Probability:** Likelihood of the threat occuring in the future. **Trend over time:** Increases and decreases in the extent, impact, permanence of an activity.	Each threat is scored for each variable using a 1-4 ranking and then the scored are multiplied to give an overall score for each threat.
Foundation of Success Framework (Salafsky and Margoluis, 1999)	**Direct Threats:** Factors that immediately affect the target condition or physically cause its destruction, including habitat fragmentation, invasive species, pollution, overexploitation, and global climate change. **Indirect Threats:** Defined as factors that underlie or lead to the direct threats.	**Area:** Percentage of the habitat(s) in the site that the threat will affect: will it affect all of the habitat(s) at the site or just a small part? **Intensity:** Refers to the impact of the threat on a smaller scale: within the overall area, will the threat completely destroy the habitat(s) or will it cause only minor changes? **Urgency:** Refers to the immediacy of the threat: will the threat occur tomorrow or in 25 years?	Threats ranked from highest to lowest for each variable; scores are summed across the 3 variables to give an overall score for each threat.

Box 4. Protected Area Threats: Findings in Brifef

The major threats and pressures facing the four protected areas are grazing, road construction, extraction of non-timber forest products (NTFPs), and poaching, in decreasing order of degree of impact (average). For actual scores, see Ervin, 2003b.

Summary of strengths and weaknesses across the four protected areas:
PA, protected area; S, strength, where 60% or more respondents answered "yes" or "mostly yes"; W, weakness, where 60% or more respondents answered "no" or "mostly no." A dash (-) indicates that the element was neither a strength nor a weakness.

Elements of assessing management effectiveness	Strength (S)/ Weakness (W)
Objectives	
PA objectives provide for biodiversity protection.	S
Management plan includes specific biodiversity-related objectives.	-
Management policies are consistent with PA objectives.	S
Employees understand the PA objectives.	S
Local communities support the PA objectives.	-
Legal security	
The PA has long-term, legally binding protection.	S
There are no unsettled disputes regarding tenure or use rights.	-
The boundary demarcation is adequate to meet PA objectives.	-
Resources are adequate to conduct critical law enforcement activities.	W
Conflicts with local communities are resolved effectively.	S
Design	
The siting of the PA is consistent with the objectives.	S
The PA layout and configuration optimize biodiversity conservation.	S
The PA zoning system is adequate to achieve PA objectives.	W
The land use in surrounding areas enables effective PA management.	-
The PA is linked to other conserved or protected lands.	S
Staffing	
The level of staffing is sufficient to effectively manage the area.	W
Staff members have adequate skills to conduct critical management activities.	S
Staff members have adequate training and development opportunities.	S
Staff performance is adequately monitored.	-
Staff employment conditions are sufficient to retain staff.	S
Communication and information	
There are adequate means of communication between field and office.	W
Ecological and social data are adequate for management planning.	W
There are adequate means of collecting new data.	-
There are adequate systems for processing and analyzing data.	-
There is effective communication with local communities.	S
Infrastructure	
Transportation is adequate to perform critical management activities.	S
Field equipment is adequate to perform critical management activities.	-
Staff facilities are adequate to perform critical management activities.	-

Protected Area Threats: Findings in Brief (continued)

Maintenance and care of equipment is adequate for long-term use.	S
Visitor facilities are appropriate for the level of visitor use.	S
Finances	
Funding is adequate to conduct critical management activities.	S
Management planning	
There is a comprehensive, recent management plan.	S
There is an inventory of natural and cultural resources.	W
There is a strategy for addressing PA threats and pressures.	W
There is a detailed work plan with specific targets and objectives.	S
The results of research are routinely incorporated into planning.	-
Research and monitoring	
The impacts of PA uses are adequately monitored.	W
Research on key ecological issues is consistent with PA needs.	W
Research on key social issues is consistent with PA needs.	-

FIRST PRIORITY RECOMMENDATIONS (CONCERNS NEEDING IMMEDIATE ATTENTION)
- Strengthening anti-poaching and law enforcement measures
- Updating research activities
- Gaining local community support through creating opportunities and benefits
- Zoning
- Financial management practices
- Availability of equipment and facilities
- Strengthening the Nature Conservation Division

SECOND PRIORITY RECOMMENDATIONS (CONCERNS NEEDING TO BE ADDRESSED IN THE NEAR FUTURE)
- Sustainable harvesting of NTFPs
- Road construction
- Fire management
- Bio-prospecting
- Continued assessment of protected areas

of measures under planning, inputs, and processes. The questionnaire also includes a series of questions that look at system-level design issues, protected area policies, and the broad policy environment.

The most thorough and effective approach to implementing this methodology is to hold an interactive workshop or series of workshops in which protected area managers, policy makers, and other stakeholders participate fully in evaluating the protected areas, analyzing the results, and identifying subsequent next steps and priorities.

The Importance of Assessing Threats in Biodiversity Conservation

As described in the various sections above, threat assessment plays a critical role in conservation planning and management. A significant issue that emerges is the diversity of approaches currently being used to conduct threat assessment by various organizations. To a large extent, methods developed and implemented by a particular organization reflect the organization's mission, and typically, conservation organizations vary enormously in their approach to conservation (Redford et al., 2003).

Table 4 attempts to contrast three current practices in threat assessment. Methods differ in definitions of threat categories, variables used to measure threats, and measurement methods. The lack of a standardized, consistent framework for threat assessment has significant drawbacks for effective conservation planning and management (TNC, 2003c). While they allow comparisons among sites using the same methodology (normally implemented by a single organization), the variety of threat definitions, measurement variables, and measurement methods across organizations often make it extremely difficult to make rigorous comparisons across sites using different methodologies.

Nonetheless, threat assessment methods provide managers with objective, repeatable ways to assess their effectiveness and allow much more efficient management at both the site and the system levels.

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Glossary

Biodiversity: the variety of life on Earth at all its levels, from genes to ecosystems, and the ecological and evolutionary processes that sustain it.

Biogeography: the study of the distribution of organisms in space and through time.

Ecoregion: a relatively large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions. The ecosystems within an ecoregion have certain distinct characteristics in common.

Endemism: refers to the degree to which species distributions are naturally restricted to a limited area.

Extinction: the complete disappearance of a species from Earth.

Fragmentation: the subdivision of a formerly contiguous landscape into smaller units.

Frontier Forests: they are the world's remaining large intact natural forest ecosystems - undisturbed and large enough to maintain all of their biodiversity and have been identified by the World Resources Institute (Bryant et al., 1997).

Hotspots: in general terms these are areas that have high levels of endemism (and hence diversity) but which are also experiencing a high rate of loss of ecosystems. A terrestrial biodiversity hotspot is an area that has at least 0.5%, or 1,500 of the world's ca. 300,000 species of green plants (Viridiplantae), and that has lost at least 70% of its primary vegetation (Myers et al., 2000).

Indicator: measurable entities related to a specific information need (for example, the status of a key ecological attribute, change in a threat, or progress towards an objective). A good indicator meets the criteria of being measurable, precise, consistent, and sensitive.

Invasive species: species whose populations have expanded dramatically, and out-compete, displace, or extirpate native species, potentially threatening the structure and function of intact ecosystems.

Key Ecological Attributes: aspects of a target's biology or ecology that, if missing or altered, would lead to the loss of that target over time. As such, key ecological attributes define the target's viability or integrity. More technically, the most critical components of biological composition, structure, interactions and processes, environmental regimes, and landscape configuration that sustain a target's viability or ecological integrity over space and time.

Last Wild Places: there are 568 Last Wild Places as identified by the Wildlife Conservation Society. These areas represent the largest and relatively wildest places in each of their biomes. Biomes are large, regional ecosystem types, defined within biogeographic realms, for example, the Afrotropical Tropical Moist Forests, or the Neotropical Flooded Grasslands. Last Wild Places represent the 10 largest, 10% wildest areas within each biome (Sanderson et al., 2002).

Objectives: specific statements detailing the desired accomplishments or outcomes of a particular set of activities within a project. A typical project will have multiple objectives. Objectives are typically set for abatement of critical threats and for restoration of degraded key ecological attributes. They can also be set, however, for the outcomes of specific conservation actions, or the acquisition of project resources. If the project is well conceptualized and designed, realization of all the project's objectives should lead to the fulfillment of the project's vision. A good objective meets the criteria of being: impact oriented, measurable, time limited, specific, practical, and credible.

Population: a group of individuals of the same species that share aspects of their demography or genetics more closely with each other than with other groups of individuals of that species. A population may also be defined as a group of individuals of the same species occupying a defined area at the same time.

Project Capacity: a project team's ability to accomplish its work. Elements include project leadership and staff availability, funding, community support, an enabling legal framework, and other resources.

Range: refers to the location of the smallest area within an imaginary boundary line that encloses all populations of a species.

Strategies: broad courses of action that include one or more objectives, the strategic actions required to accomplish each objective, and the specific action steps required to complete each strategic action.

Threats: factors that negatively alter the normal state of biodiversity including species, sites, ecosystems, landscapes etc.

Viability: the status or "health" of a population of a specific plant or animal species. More generally, viability indicates the ability of a conservation target to withstand or recover from most natural or anthropogenic disturbances and thus to persist for many generations or over long time periods.

Ecosystem Loss and Fragmentation

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Introduction

Ecosystem loss and fragmentation has been termed the greatest worldwide threat to biodiversity and the primary cause of species extinction (Wilcox and Murphy, 1985; Rosenberg and Raphael, 1986; Simberloff, 1986). Today, as Laurence and Bierregaard (1997) have stated, "the fragmented landscape is becoming one of the most ubiquitous features of the tropical world – and indeed, of the entire planet." Moreover, ecosystem fragmentation is as much an issue for biodiversity in aquatic, including marine, environments as it is for terrestrial ones (Bostrom et al., 2006).

Ecosystem loss and fragmentation are related processes and typically occur simultaneously. Indeed, some texts (e.g., Meffe and Carroll, 1997) define fragmentation as the loss and isolation of natural habitats. However, the two processes are distinct (Fahrig, 2003). Ecosystem loss refers to the disappearance of an *ecosystem*, or an assemblage of organisms and the physical environment in which they exchange energy and matter. Many studies, however, examine loss with respect to a specific organism's *habitat*. *Habitat loss* is the modification of an organism's environment to the extent that the qualities of the environment no longer support its survival. Habitat loss usually begins as *habitat degradation*, the process where the quality of a species' habitat declines. Once the habitat's quality has become so low that it no longer supports that species then it is termed habitat loss. *Fragmentation* is usually a product of ecosystem loss and is best thought of as the subdivision of a formerly contiguous landscape into smaller units. Ultimately, fragmentation reduces continuity and interferes with species dispersal and migration, thereby isolating populations and disrupting the flow of individual plants and animals (and their genetic material) across a landscape. Generally speaking, habitat loss is of far greater consequence to biological diversity than habitat fragmentation (Fahrig, 2003).

This process is well illustrated in southeastern Bolivia, where a landscape that was once continuously forested has been transformed into patches of forest surrounded by a matrix of agricultural land. A *patch* is usually defined by its area, perimeter, shape, and composition (e.g., a land cover type - such as water, forest, or grassland - a soil type, or other variable). The *matrix* is simply the most common cover type in any given landscape.

Loss and fragmentation are tightly coupled processes as the pattern of loss affects the degree of fragmentation. For example, in a 200-hectare forest, a single 100-hectare block could be cleared at one site for a farming operation. Alternatively, forest could be cleared into many small plots across the landscape, leaving 100 forest fragments of one hectare each. In both cases the landscape has lost 100 hectares of forest, but in the second scenario the landscape has a much higher level of fragmentation. The potential consequences for plants and animals are quite different in these two scenarios.

Habitat Loss by Biome

Loss and fragmentation impact most of the earth's major *biomes* from tropical and temperate forests to grasslands and from wetlands to rivers. Quantifying the extent of this loss and fragmentation is difficult – one major problem is determining what vegetation existed historically to establish a benchmark for comparisons. Another issue is determining the extent that change is caused by humans versus natural forces (Clark and Matthews, 1990; Fukami and Wardle, 2005). Many textbooks show maps of the hypothetical distribution of the world's biomes with today's climate, if there were no humans. These maps refer to the "present potential" vegetation – that is the potential vegetation if there were no humans to remove it. Additional maps illustrate earlier times when climates were different and human impact was minimal: 5,000, 10,000 or more years ago. What is the basis of these maps and how accurate are they?

Maps for 5,000 or more years ago are largely determined by past climate, as human influence was still limited. Evidence of past climate patterns are compiled from plant and zoological fossils, as well as soil and sedimentological analyses. Maps of present potential vegetation combine existing vegetation and climate patterns with remnant vegetation patches. With these maps there are obviously higher levels of uncertainty in areas that are heavily influenced by human activity versus those that have limited human impact. In other words, areas that have been heavily affected by human activity for thousands of years, such as Europe, are more difficult to recreate, while areas like the Arctic tundra or Canada's boreal forest are easier to establish. For a detailed discussion of the challenges in reconstructing and understanding global vegetation patterns, see Adams and Faure (1997).

Efforts have been made to quantify the extent and rate of loss of the world's major biomes at various scales and for different time periods (Turner and Clark, 1990; Skole and Tucker, 1993; Adams and Faure, 1997; Davidson et al., 1999; Steininger et al., 2001; Achard et al., 2002; Etter et al., 2006). This process is complex and estimates vary widely due to:

- differences in classification methods (for example, wetland inventories in the United States, Canada, and Mexico are all based on slightly different definitions for wetlands);
- limited data for some regions (for example, typically there is less data for Africa than North America);
- lack of comparable land cover data from different time periods (particularly historical data) that would allow comparisons over time;
- limited groundtruthing of satellite data; and
- poor or erratic government reporting.

These factors must all be kept in mind when examining data on the extent and rate of ecosystem loss and fragmentation. Despite these challenges, these data are critical to conservation efforts and monitoring. Because of its importance, in recent years efforts have been made by several organizations, such as the World Resources Institute (WRI), Wetlands International, and Tropical Ecosystem Environment Observation by Satellite (TREES), to streamline habitat classification and produce better comparisons on broad scales (Davidson et al., 1999; Matthews et al., 2000; White et al., 2000; Achard et al., 2003).


Deforestation in Madagascar (Source: L. Langham)

Terrestrial

Forests - Tropical and Temperate

Today forest cover has shrunk to approximately half of its *potential extent* (Adams and Faure, 1997; Roper and Roberts, 1999), replaced by agriculture, grazing, and settlement.

Table 1: Deforestation rates	
Hotspot areas by continent	Annual deforestation rate for sample sites within hotspot area (range)
Latin America	0.38%
Central America	0.8-1.5%
Brazilian Amazon belt	
Acre	4.4%
Rondonia	3.2%
Para	1.4-2.7%
Columbia-Ecuador border	1.5%
Peruvian Andes	0.5-1.0%
Africa	0.43%
Madagascar	1.4-4.7%
Southeast Asia	0.91%
Southern Vietnam	1.2-3.2%
Source: Modified from Achard et al., 2002	

Primary forest blocks of a significant size exist in only a few countries, such as the boreal forests of Northern Canada and Russia, and the Amazon basin of Brazil (Bryant et al., 1997).

The world's forests began declining thousands of years ago, with the expansion of farming and herding in the Middle East and Europe. More recently, rapid population growth, industrialization, and globalization are contributing to rapid deforestation in many tropical regions, with forest loss in Brazil and Indonesia exceeding 3.5 million hectares in 1995 alone (Roper and Roberts, 1999, based on FAO figures). While there is no question that forest loss and fragmentation is substantial, determining the exact rate of these losses globally is complex (Roper and Roberts, 1999). While determining rates at smaller, local scales is often easier (Skole and Tucker, 1993; Steininger et al., 2001), they too can be controversial.

Furthermore, depending on how "forest" is defined, what forest cover data is presented, or how it is analyzed, the picture we obtain may end up being quite different; for example, by changing the time periods used in an analysis, deforestation rates may differ dramatically. According to estimates from the Tropical Ecosystem Environment Observation by Satellite (TREES), a research program that uses satellite imagery to estimate the extent of the world's tropical humid forests, between 1990 and 1997, 5.8 (+/- 1.4) million hectares of humid forest were lost each year, which corresponds to a rate of 0.52% per year. A further 2.3 (+/-0.71) million hectares were obviously degraded, a rate of 0.20% a year (Achard et al., 2002; Eva et al., 2003). However, other scientists considered this result to be an underestimate of tropical forest loss, as it only included humid tropical forest, while dry tropical forests are disappearing more rapidly as those areas are often more conducive to agricultural activities (Fearnside and Laurance, 2003). For conservation planning, it is also critical to keep in mind the variation in deforestation rates at regional and local scales as different strategies might be needed. For example, the average deforestation rate across all of Latin America is 0.38%, yet there is a very different picture of deforestation if you look at the provincial level. Rates of deforestation in Brazil's Acre province are 4.4 percent, substantially higher (Table 1). Knowledge of this variation is essential for conservation planning.

Grasslands - Tropical, Temperate, and Tundra

Estimates of the extent of the world's grasslands range from 40 to 56 million km^2 or 30 to 40 percent of the earth's land area (Table 2) (Whittaker and Likens, 1975; Atjay et al., 1979; Olson et al., 1983; Davidson et al., 2002). These estimates incorporate temperate and tropical grasslands as well as shrubland and tundra (tundra occurs around the Arctic circle above the latitude where trees can survive, and is dominated by shrubs, sedges, grasses, lichens, and mosses). Temperate grasslands develop in climates that typically have cold winters and summer droughts, and are found in North America (prairies), Europe and Asia (steppe), South America (pampas), and South Africa (veldt) (Roxburgh and Noble, 2001). Tropical grasslands usually develop in areas with distinct seasons of drought and rain, and include savanna, as well as tropical woodland and savanna (this designation refers to grassland associated with shrubs and trees). Herbivory and fire are important elements of temperate and tropical grassland systems.

Table 2: Extent of the world's grasslands								
	Whittaker and Likens (1975)[a]		Atlay et al. (1979)[a]		Olsen et al. (1983)		Davidson et al. (2002)[f]	
Grassland Type	Million km^2	% of Total Land Area[b]	Million km^2	% of Total Land Area[b]	Million km^2	% of Total Land Area[b]	Million km^2	% of Total Land Area[b]
Savanna	15.0	11.6	12.0	9.3	–	–	17.9	13.8
Tropical Woodland and Savanna	–	–	–	–	7.3	5.6	–	–
Dry Savanna and woodland	8.5[c]	6.6	3.5	2.7	13.2[d]	10.2	–	–
Shrublands[e]	–	–	7.0	5.4	–	–	16.5	12.7
Non-woody grass-land and shrubland	–	–	–	–	21.4	16.5	10.7[g]	5.7
Temperate Grassland	9.0	7.0	12.5	9.7	–	–	–	–
Tundra	8.0	6.2	9.5	7.3	13.6	10.5	7.4	5.7
Total Grassland	40.5	31.3	44.5	34.4	55.5	42.8	52.5	40.5

[a] Desert and semi-desert scrub not included
[b] Total land area used for the world is 129,476,000 km^2 (excludes Greenland and Antarctica)
[c] Includes woodland and shrubland
[d] Includes dry forest and woodland
[e] Includes hot, warm, or cool shrublands
[f] Davidson et al. (WRI/PAGE) calculations based on GLCCD, 1998, Olsen, 1994 a and b, PAGE land area is based on land cover classifications for savanna, woody savanna, closed and open shrubland, and non-woody grassland, plus Olsen's category for tundra
[g] Includes non-woody grassland only
Notes: – means data is not available or has been combined in another category

Some of the highest rates of habitat loss and fragmentation in the world have been in grassland areas, in large part because of their suitability for growing crops like wheat and corn, and for grazing (Parkinson, 1997). Conversion of grasslands to farmlands in Western Canada and the U.S. has left only remnants of the original prairie grassland. The U.S. Geological Survey (USGS) estimates that since 1830 over 1 million km^2 of the grasslands of the western US have disappeared.

- The tall-grass prairie grassland has decreased by 97 percent (from 677,300 km^2 to 21,548 km^2)
- Mixed-grass prairie has declined 64 percent (from 628,000 km^2 to 225,803 km^2)
- Short-grass prairie has declined 66 percent (from 181,790 km^2 to 62,115 km^2)

Additional declines are occurring in grasslands in other parts of the world as well. The rate and extent of these declines is less well documented than in the U.S. and so is harder to quantify accurately.

Aquatic

Although we often think of loss and fragmentation only in a terrestrial context, as these areas are easier to observe, loss and fragmentation is also a concern for aquatic ecosystems. Wetlands, mangroves, seagrasses, rivers, coral reefs, kelp forests, and rocky shorelines are fragmented by natural forces such as

Table 3: Wetland extent (in hectares) in the United States and Canada based on the results of national wetland inventory information					
Country	Wetland Extent (1780s)	Wetland Extent (1980s)	Wetland Extent (1985)	Wetland Extent (1988)	Wetland Extent (>1988)
United States (continental only)	89,488,127 [a]	42,238,851 [a]	41,356,092 [b]	-	40,9000,000 [b]
United States (includes Alaska and Territories)	158,389,525 [a]	111,056,479 [a]	-	-	-
Canada	-	-	-	127,199,000 [c]	150,000,000 [d]

[a] published Dah, 1990;
[b] USFWS, 1998;
[c] published NWWG, 1988;
[d] approximate number based on data indicating total wetland extent in Canada may be as much as 150,000,000 ha based on information indicating increase in peatland area (Polestar Geomatics, unpublished)

Source: Modified from Davidson et al., 1999

bottom topography, wave action, currents, tides, storm surge, as well as human activities such as draining, diversion, extraction of groundwater, dams, dredging, sedimentation, fishing (e.g., trawling, dynamite fishing), aquaculture, sea jetties, and boating. Here we highlight loss and fragmentation in two of the many aquatic systems: wetlands and rivers.

Wetlands

Wetlands have been drastically reduced in area and number in many regions of the world as they are drained and filled for human use. A recent global review of wetlands identified significant gaps in our knowledge of their extent and rate of loss (Davidson et al., 1999). Differences in classification schemes as well as gaps in data (data is especially limited for areas outside North America and Europe) mean that current estimates of global wetland coverage vary widely, from 560 to 1,279 million hectares. In the continental United States, where study of wetlands has been more extensive, wetlands have declined by more than half, from 89 to 42 million hectares between 1780 and 1980. The rate of loss is speeding up; by 1985 more than an additional one million hectares disappeared (see Table 3).

Riverine Systems

Many of the world's major riverine systems are highly fragmented or have had their flow modified by human intervention, primarily through the creation of dams (Dynesius and Nilsson, 1994; Pringle, 1997). According to the World Register of Dams, between 1950 and 1986, the number of large dams in the world increased seven-fold. Most dams are built for irrigation or for hydroelectric needs; they fragment rivers and surrounding environments and change natural water flow patterns, transforming *lotic* into *lentic* systems. Of the world's major rivers (those greater than 125 miles or 201 km long), only two percent are free flowing; the remaining 98 percent have been fragmented or diverted (Benke, 1990).

Fragmentation of rivers has impacted many species. In the Pacific Northwest of the United States, dams have seriously affected salmon populations by preventing salmon from returning to their native streams to reproduce. Dams have also contributed to declining freshwater mussel populations. Ninety percent of the world's freshwater mussels are found in North America, and 73 percent of these face extinction in the United States. Many North American freshwater mussels must spend a part of their lifecycle in fish gills to reproduce successfully. As an example, dams have blocked the movement of *anadromous fish*, which the dwarf wedge mussel (*Alasmidonta heterodon*) depends upon during its life cycle. This, coupled with siltation and chemical runoff, has led to substantial declines in their population.

Freshwater systems are also fragmented by groundwater removal, which often modifies the temperature structure of streams. For example, in the Southeastern United States extraction of groundwater has reduced the amount of cold water that feeds many streams. Important game species, like striped bass, use spring-fed areas of rivers as refuges during hot summer months, as they have high oxygen needs and higher oxygen levels are found in colder water (Pringle, 1997). As these colder areas disappear, it affects species that depend upon these conditions.

Causes of Fragmentation

Fragmentation is caused by both natural forces and human activities, each acting over various time frames and spatial scales.

Fragmentation Due to Natural Causes

1. Over long time frames (thousands or millions of years), landscapes are fragmented by geological forces (e.g., continental drift) and climate change (e.g., glaciations, changes in rainfall, sea level rise).
2. Over short periods (decades or months), natural disturbances, such as forest fires, volcanoes, floods, land slides, windstorms, tornadoes, hurricanes, and earthquakes, modify and fragment landscapes.

In addition, landscapes are naturally fragmented by mountain ridges, canyons, rivers, and lakes. Some ecosystems also commonly occur in discrete patches and are thus naturally fragmented. Natural processes create the habitat heterogeneity and landscape diversity upon which many species depend.

Fragmentation Due to Human Activity

Humans have modified landscapes for thousands of years. Early hunters influenced the landscape by burning areas to favor certain game species, and today ranchers keep grasslands open in the same way (Schüle, 1990). Many human activities—agriculture, settlement (e.g., construction of buildings, fences etc.), resource extraction (e.g., mining, timber), industrial development (e.g. the construction of hydroelectric dams)—alter and fragment landscapes. Of these activities, agriculture is the leading cause of ecosystem loss and fragmentation throughout much of the world today (Vitousek et al., 1997; Tilman et al., 2001).

The process of human-caused fragmentation often proceeds in a fairly predictable manner. First, an opening is formed in a matrix of natural habitats: perhaps a road is built that crosses the landscape. This opening becomes larger as settlement and deforestation occur along the road. Still, the landscape remains largely forested and although there is habitat loss, fragmentation is minimal. Second, smaller roads are constructed off the main road, increasing access to the forest. The newly accessed areas are subsequently cleared for crops. The landscape begins to appear fragmented, even though the remaining patches of original forest are still large. This process of subdivision repeats itself at a finer and finer scale until the landscape shifts to one predominated by cleared or degraded land, with patches of isolated forest. Eventually, all of the landscape may be converted for human use, except those spots that are too wet, too dry, or too steep to be useable.

Humans also create distinctive patterns as they fragment landscapes, typically leaving patches that are non-random in size and distribution. An analysis of deforestation in the Tierras Bajas region of Southwest Bolivia revealed different land cover patterns created by four principal groups of people (Steininger et al., 2001). Colonization by peasant farmers, in some cases planned and in others not, left a complex mosaic of cropland, secondary forest, and forest remnants. The planned settlements formed pinwheel patterns of linear farms, radiating from a central town, while the unplanned settlements appeared as small, square or rectangular fields along roads. Mennonite colonies, on the other hand, had settlements along the road with large, rectangular farms extending behind them, leaving larger forest remnants than the peasant settlement patterns. Industrial soybean farms were distinguished from the others by their lack of settlements; these farms formed linear strips with marked boundaries and windbreaks of trees 20 to 40 meters wide between the strips. Like the Mennonite farms, the industrial farms left larger forest remnants.

There are several technical terms commonly used in the field of landscape ecology to define different stages of the fragmentation process or different forms of fragmentation of a landscape. These include perforation (holes punched in a landscape), dissection (initial subdivision of a continuous landscape), fragmentation (breaking into smaller parts), shrinkage (reduction in size of patches), and attrition (loss of patches).

Natural Versus Human Fragmentation

Several differences exist between human-caused and naturally fragmented landscapes:

1. A naturally patchy landscape often has a complex structure with many different types of patches. A human-fragmented landscape tends to have a simplified patch structure with more distinct edges, often with a few small patches of natural habitats in a large area of developed land.
2. Patch types in human-modified landscapes are often unsuitable to many species, while in a heterogeneous natural landscape most patch types are suitable to a more diverse group of species.
3. The borders (or edges) of patches in naturally patchy landscapes tend to be less abrupt than in those created by humans. (Edge effects are discussed in detail later in this document.)

Certain features of human-fragmented landscapes, such as roads, are novel in the evolutionary history of most wild species and pose additional threats. Not only do they restrict movement between populations, but heavily traveled roads are a direct danger to wildlife (Forman and Alexander, 1998; Gibbs and Shriver, 2002). Furthermore, some animals avoid habitats near roads due to noise pollution. Roads also have secondary impacts on ecosystems and species. They are an access point, increasing a region's vulnerability to invasion by exotic species, and perhaps most importantly, making wildlife habitats accessible to people for hunting or resource extraction (Findlay and Bourdages, 2000). In West Africa, for example, new roads for logging act as conduits for the bushmeat trade, which has contributed to the extirpation of many duiker species (*Cephalopus spp*.) and the extinction of at least one primate species, Miss Waldron's red colobus monkey (*Procolobus badius waldroni*) (Newing, 2001; Whitfield, 2003).

Effects of Fragmentation

Fragmentation and loss of ecosystems are coupled processes: fragmentation is a consequence of loss (Haila, 1999). It is often difficult to distinguish between the effects of these two processes, since they often happen simultaneously. Loss of habitat impacts species principally by reducing available resources and microenvironments. Fragmentation has additional consequences for species on top of those caused by loss—most importantly, affecting movement and dispersal and modifying behavior.

As fragmentation progresses in a landscape, three major consequences are apparent:

1. decreasing patch size;
2. increased edge effects; and
3. increased patch isolation

Decreasing Patch Size

Once a landscape has been fragmented, the size of the remaining patches is a critical factor in determining the number and type of species that can survive within them. For all species—large or small—that cannot or will not cross a forest edge or leave a patch, all requirements to complete their life cycle must be met within the patch, from finding food to mates. This is especially important for species with complex life cycles, each with distinct habitat requirements. For example, many amphibian species have an aquatic larval stage and an upland adult phase. Also, some species require large areas of continuous habitat and cannot survive in small patches—they are referred to as *area-sensitive species*. Furthermore, large patches typically support larger populations of a given species and thereby buffer them against extinction, *inbreeding depression*, and *genetic drift*.

Increased Edge Effects

One of the most obvious changes to a fragmented landscape is the increase in edge environment. *Edge environments* or *ecotones* mark the transition between two different habitats. In a naturally forested landscape, edge is usually limited to a small area, such as along streams or landslides (Laurance and Bierregaard, 1997). Natural edges are usually less abrupt than human-formed edges and show a gradual transition from one habitat type to another. In Rondonia, Brazil, deforestation patterns show a herringbone pattern that closely follows the road that was cut through the original forest. Along agricultural frontiers, the original landscape may be fragmented into long narrow strips or shreds, interspersed with areas of agriculture (Feinsinger, 1997). These strips may separate different crops, thus serving as windbreaks, or the boundary between two landowners. As a result this remaining fragment is entirely made up of edge environment. Residual trees along rivers provide another example of narrow, edge-dominated environments.

The extent of edge environment in a fragment patch is determined in part by its shape. The ratio of the perimeter to area (or the amount of edge environment to the amount of interior) is one measure of patch shape. A circular patch has the maximum area per unit edge and will have less edge environment and fewer edge effects than a rectangular patch of the same size. Because edge effects may extend 200 meters (and sometimes more), small patches may be entirely composed of edge environment. For example, a new reserve is being created with an area of one square km. The reserve can either be rectangular: Reserve A (2 km by 0.5 m), or square: Reserve B (1 km by 1 km). As illustrated, both have the same total area but Reserve A will be composed entirely of edge environment and its core size will be 0 square km, whereas Reserve B will have a core area of 0.25 square km.

Edge Effects

Many studies have examined the effects of edges on the physical environment and biological communities that remain after fragmentation (Lovejoy et al., 1986; Bierregaard et al., 1992; Malcolm, 1994; Camargo and Kapos, 1995; Murcia, 1995; Didham, 1997; Laurance et al., 1998; Carvalho and Vasconcelos, 1999). The longest running and perhaps the most detailed study of fragmentation effects ever conducted is the Biological Dynamics of Forest Fragments project, which began in 1979. This pioneering project, located in the Amazon region north of Manaus, Brazil, has generated some of the findings described here and informed much of our general understanding of the effects of forest fragmentation. Edge effects is a general term used to describe a number of different impacts, and can be categorized into several types: physical (e.g., microclimatic changes), direct biological (changes in species composition, abundance, and distribution), and indirect biological (changes in species interactions such as predation, competition, pollination, and seed dispersal) (Matlack and Litvaitis, 1999). Moreover, many of the effects of fragmentation are synergistic; for example, fragmentation can lead to increased fire risk, increased vulnerability to invasive species, or increased hunting pressure (Hobbs, 2001; Laurance and Williamson, 2001; Peres, 2001).

Edge Effects - Physical

Some of the most significant edge effects are the microclimatic changes that take place along a fragment's edge (Harper et al., 2005). Edge areas in forests are typically warmer, more exposed to light and wind, and drier than interior areas. Gradients of these microclimatic conditions extend into the interior approximately 15 to 75 meters (Kapos, 1989; Laurance and Bierregaard, 1997). Microclimatic changes along edges often have secondary effects, such as altering vegetation structure and, eventually, plant and animal communities (Matlack, 1993).

Increased wind along the edge of fragments physically damages trees, causing stunted growth or tree falls (Essen, 1994; Laurance, 1994). This is especially obvious when a fragment first forms, since interior plant species are often not structurally adapted to handle high wind stress. Furthermore, wind tends to dry out the soil, decrease air humidity, and increase water loss (evapotranspiration rates) from leaf surfaces, creating a drier microclimate. This drier environment has a higher fire risk. Several studies have examined the increased risk of fires in fragmented environments, particularly those that border grazing lands (Uhl and Bushbacher, 1985; Cochrane and Schulze, 1999; Nepstad et al., 1999; Cochrane, 2001; Hobbs, 2001).

Edge Effects - Biological

The creation of "edge" following fragmentation causes a number of biological changes (Harper et al., 2005). These changes are often similar or coupled to the biological changes that result from the creation of the fragment itself. These include changes in species composition, abundance, and distribution, as well as changes in species interactions such as predation, competition, pollination, and seed dispersal. Along the edge of a fragment, biological changes may extend farther than the physical ones. In one study, invasion by a disturbance-adapted butterfly species extended nearly 250 meters into the forest (Laurance et al., 2000). Here we examine three biological changes particularly associated with the formation of edge: invasion by generalist species, alteration of plant communities, and alteration of insect communities and nutrient cycling. Additional biological changes as a consequence of fragmentation are detailed in subsequent sections: "Effects on Species Abundance, Richness, and Density" and "Interactions Among Species and Ecological Processes."


Bolivian road (Source: E. Sterling and K. Frey)

Invasion by Generalist Species

Edges are more susceptible to invasion by generalist or "weedy" species that are better adapted to handle disturbance and the new microclimate. These species might be plants (such as lianas, vines, creepers, and exotic weeds), animals, or diseases. Simultaneously, long-lived interior canopy species, epiphytes, and other mature forest taxa decline in abundance (King and Chapman, 1983). Wind along edges also increases the transfer of seeds from outlying areas, thereby aiding invasion of foreign, generalist, or weedy species. Introduction of animals, adapted to disturbed environments and human presence, such as domestic cats, rats, and mice, is often a problem along edges, as is disease transmission between wildlife and domestic animals.

Alteration of Plant Communities

The increased light along edges affects both the rate and type of plant growth, favoring fast-growing light-loving species at the expense of slower-growing shade-loving ones (Harper et al., 2005). Studies of forest fragments in the Amazon noted a dramatic loss of plant biomass overall; although secondary vegetation (especially vines and lianas) proliferated, this new biomass did not compensate for the loss of "interior" tree species (Laurance et al., 1997). Since many tree species have long life spans, it is important to examine the changes in plant communities over extended periods. It may take hundreds of years for the full consequences of fragmentation to be revealed.

Alteration of Insect Communities and Nutrient Cycling

Only a few studies have been conducted to date on the effect of fragmentation on insect communities (Aizen and Feinsinger, 1994; Gibbs and Stanton, 2001). Fragmentation, however, appears to alter both the abundance and composition of insect communities, thus affecting leaf litter decomposition and hence nutrient cycling (Didham, 1998).

Beetles (of the families, Carabidae, Staphylinidae, Scarabaeidae) that are common to continuous interior forest disappear from forest fragments, a surprising result given their small size and generalist habitat requirements (Klein, 1989). Their disappearance may be the result of the drier microclimate or loss of species they depend on (i.e., less mammal dung and fallen fruit on which to reproduce). Another possible reason for their disappearance is that these insects actually travel tremendous distances in search of decaying material for their reproduction and may not be able to cross the matrix between patches. Whatever the cause, there are a number of implications for ecosystem function, including a decreased rate of nutrient cycling. Also, the incidence of disease may be elevated, as dung is left on the ground longer, allowing flies to breed there.

Isolation-Barriers to Dispersal

The degree of isolation of a patch helps determine what biological communities it can sustain. While patches may appear isolated, their actual biological *connectivity* depends on the habitat that separates them. In fragmented landscapes, patches of high-quality habitat are typically interspersed with areas of poor habitat. In a very isolated patch, species that cannot disperse may be unable to find adequate resources or mates. They may become separated from other populations and thus prone to genetic inbreeding and possibly local extinction.

Species Response to Isolation

A species' response to fragmentation depends on its dispersal ability as well as its perception of the environment. For example, species that fly (e.g., birds, bats, flying insects) are typically less affected by patch isolation than less mobile species (e.g. frogs and beetles). For some species, crossing an open field for two kilometers is not a problem. However, species that spend most of their time in treetops (e.g., some species of primates and marsupials) or in dark, interior forest may never cross such a large opening. A species that disperses over long distances, such as an African elephant (*Loxodonta sp.*), will perceive a particular landscape as more connected than a species with short-range dispersal, such as a shrew (species of the family Soricidae).

Species without the benefit of an aerial view of a landscape make decisions primarily based on the habitat directly in front of them (Gibbs et al., 1998). A study in the Amazon conducted by Malcolm (1998) revealed distinct responses of similar animals to fragmentation. Two species of opposum—the wooly (*Didelphys lanigera*) and the mouse (*Didelphys murina*)—were tracked using radio transmitters to determine if they would travel a gap of 135 to 275 meters to reach the fragment on the other side. Mouse opposums were able and willing to cross the gap, while the more strictly arboreal species, the wooly opposum, was not.

In the marine environment, responses to fragmentation are more complex because the environment is three-dimensional, and many marine species are mobile or have a mobile larval stage, and breed far from where they complete their adult life cycle. These traits mean that marine species are less likely to experience the kind of isolation that occurs in a fragmented terrestrial system. The circumstances depend largely on the particular marine system or species (e.g., fragmentation of mangroves mimics terrestrial fragmentation more closely than that of other marine systems) and the degree of fragmentation (small or large scale). Studies of larval dispersal that examine the link between physical oceanography (e.g., currents) and reproductive life cycles of marine species are shedding new light on the level of connectivity of marine systems (Roberts, 1997; Cowen et al., 2000; Taylor and Hellberg, 2003).

Effect of Time on Isolation

Fragmentation is a dynamic process, often with delayed effects; knowing the amount of time a patch has been isolated is critical to understanding the consequences of fragmentation. In long-lived species, such as trees, it may take a hundred years to observe the impact of fragmentation. Individual trees continue to survive immediately following fragmentation; how-

Table 4: A comparison of matrix habitats from a wildlife conservation perpective							
	Benefits						
	Allows	Provides	Provides	Provides Protection From			
Matrix Habitat	**Gene Flow**	**Ecosystem Services**	**Wildlife Habitat**	**Climatic Extremes**	**Exotic Species**	**Fire**	**Total Score**
Fully protected forest	4	4	4	4	4	4	24
Low intensity selective logging	4	4	3	4	3	3	21
Traditional forest management	3	4	3	4	3	3	20
Medium-high intensity logging	3	3	3	3	3	1	16
Low-diversity agroforestry	2	2	2	2	2	2	12
Plantation Forests	1.5	3	1.5	3	2	3	14
Row crops	1	0	1	0	0	1	3
Cattle pastures	1	1	1	0	0	0	3
Note: Each habitat was scored by a panel of 15 researchers. The most favorable habitats received the highest number and the least favorable received the lowest.							
Source: Modified from Laurance et al., 1997							

ever, they may no longer reproduce – perhaps they are too spread apart to exchange pollen by wind, or their pollinators or seed dispersers have disappeared. In this case, it is only a matter of time before the population becomes locally extinct. Janzen (1986) coined the term "living dead" to describe the fates of species in such situations.

Effects of Different Types of Fragmentation

The effects of fragmentation also vary depending on the cause of fragmentation (for example, fragmentation for agriculture versus for logging). It is difficult to make generalizations about the effects of a specific type of fragmentation on a particular landscape, since the consequences may be very different in a temperate versus a tropical region or in a grassland versus a forest, largely because the plants and animals present have different sensitivities to fragmentation.

Keeping these issues in mind, we can estimate the potential effects of a particular type of fragmentation based on how the new environment is perceived by the original species present and whether the change to the landscape is permanent or temporary. For example, selective logging is typically less disruptive than clear-cutting forested areas. This is because after selective logging the forest is still relatively intact. While differing from the original forest, selectively-logged forest does not form a large, unusable gap in habitat, as often occurs when a forested area is replaced with agricultural land (Table 4.).

The matrix that surrounds fragments has a large effect on what species remain within the fragments and their dispersal ability between fragments. Table 4 illustrates some of the benefits provided by different matrix types as subjectively ranked by a panel of 15 researchers from the Biological Dynamics of Forest Fragments project. The table displays a hierarchy of matrix habitats from most favorable to least favorable for many species.

Effects on Species Abundance, Richness, and Density

Fragmentation's impact on species abundance, richness, and density is complex, and there is no clear rule what these effects may be. Studies of the effects of fragmentation on species abundance, richness, or density relative to fragment size have had inconsistent results (Debinski and Holt, 2000), some indicating an increase in species, in others, a decline. However, it is important to keep in mind that simply counting the number of species does not measure impacts of fragmentation on behavior, dispersal ability, or genetic diversity.

Some species respond positively to fragmentation (Brown and Hutchings, 1997; Laurance and Bierregaard, 1997; Lynam, 1997; Malcolm, 1997). Fragmentation may increase species richness by allowing generalist species to invade. In a study of the impact of fragmentation on frogs in a lowland Amazonian forest, species richness was strongly and positively related to fragment area (Tocher et al., 1997). After fragmentation, species richness increased largely as a result of invasion by frog species from the surrounding matrix into the remaining forest fragments. It is unclear if this increase will be sustained over time. For example, if this same spot were re-surveyed in 50 years, total species richness might decline as interior forest species disappear.

Immediately following fragmentation, the density of individuals may increase as animals "crowd" into the remaining forest (Schmiegelow et al., 1997; Collinge and Forman, 1998). This inflation of density will ultimately prove short-lived because patches are rarely adequate to support the same population density as more extensive habitats. This phenomenon underscores the need to monitor fragmentation effects over long time scales.

Interactions Among Species and Ecological Processes

Fragmentation causes the loss of animal populations by a process termed *faunal relaxation*, the selective disappearance of species and replacement by more common species (Diamond, 2001). Large-bodied vertebrates, especially those at high *trophic levels*, are particularly susceptible to habitat loss and fragmentation, and are among the first species to disappear. Thus, predators are often lost before their prey, and those species that do survive on small fragments (usually herbivores) tend to become far more abundant than populations of the same species on larger species-rich fragments. There are two principal explanations for this increased abundance. The first is *ecological release from competition*: when competing species are removed, the resources they utilized become available to the persisting species. The second is that prey escape predators that normally limit their abundance on larger fragments. Lack of predators in small fragments can also lead to an overabundance of herbivores that tend to weed out palatable plant species and convert the landscape into a forest of "herbivore-proof" plants. Furthermore, as large predators disappear, smaller predators often increase; this is known as *mesopredator release* (Soulé et al., 1988; Terborgh et al., 1997). For example, in California, as coyotes disappear from fragments, there is an overabundance of smaller predators, such as skunks, raccoons, grey fox, and cats (Saether, 1999).

Cassava field burning in Vietnam (Source: K. Frey)

These smaller predators then prey on scrub-breeding birds. Fragmentation thus triggers distortions in ecological interactions that drive a process of species loss, the end point of which is a greatly simplified ecological system lacking much of the initial diversity (Terborgh et al., 1997; Terborgh et al., 2001).

While predator-prey relationships are often altered in fragmented landscapes, it is not always possible to predict what the change will be. A number of review papers have examined nest predation in fragmented landscapes; however, the results have been inconsistent (Andren, 1994; Paton, 1994; Major and Kendal, 1996; Hartley and Hunter, 1998; Chalfoun et al., 2002). Studies in Central Canada, for example, found that nests in forest patches adjacent to agricultural land had increased predation, while those next to logged areas did not (Bayne and Hobson, 1997, 1998). It appeared that the predator community did not change in the logged areas, while forest patches next to agricultural land had increased densities of red squirrels that preyed on the nests. Other studies have shown that songbirds are subject to increased predation along edges, particularly in deforested areas. In other words, the type of fragmentation and the habitat adjoining the fragment influences predator-prey relations: nest predation is less affected by a single road bisecting an area, but is greatly affected along edges of areas that have been deforested (Hartley and Hunter, 1998).

Overall a combination of landscape type and structure, predator community, and level of parasitism are important in anticipating the outcomes of fragmentation. For example, unlike studies in the Midwest and Northeast of the United States, a study in the American West, where the landscape has historically been patchy, found that predation rates actually decreased as human-caused fragmentation increased (Tewksbury et al., 1998). This study indicated that the type of predators in an area, as well as the habitat structure, were key inputs to anticipate the impact of fragmentation on bird nest predation rates.

In addition, not all groups of species experience an increase in predation due to fragmentation. A recent analysis of the literature found that avian predators were more likely to benefit from fragmentation than mammalian predators (Chalfoun et al., 2002). Another study surprisingly found that turtle nests located along roads had lower predation rates than those lo-

Box 1. Corridors and Connectivity

When existing protected areas are small, connecting them to other protected areas may increase their ability to sustain their fauna and flora. Connectivity between protected areas is critical as few of them are large enough to sustain species on their own (Hunter and Gibbs, 2006). Four basic species movements are important to consider to ensure landscape connectivity: daily, small-scale home range movements; annual seasonal migrations; dispersal of young from their parents; and geographic range shifts (Hunter, 1997). These different species movements as well as the types of species found in a particular landscape are all important factors when increasing connectivity or designing protected area networks. One way to increase connectivity is by creating wildlife corridors. *Corridors* are linear strips of land that allow species to move among different habitat types for breeding, birthing, feeding, roosting, annual migrations, dispersal of young animals away from their parents, and as an escape path from predators or disturbance. Riparian zones are good examples of corridors that link forest patches. The value of corridors has been the center of considerable debate (Noss, 1987; Simberloff and Cox, 1987; Soulé and Gilpin, 1991; Simberloff et al., 1992; Tewksbury et al., 2002). Part of this debate is due to the theoretical nature of the corridor concept. There are few studies that show that animals actually use corridors, or that can separate between the effect of the corridor itself from that of the additional habitat provided by its creation.

cated in edges or in forests (Hamilton et al., 2002).

An increase in invasive plants following fragmentation may indirectly enhance predator success on bird nests. Schmidt and Whelan (1999) found that invasive plants of the genera *Lonicera* and *Rhamnus* were not only preferred nesting sites for American robins (*Turdus migratorius*) and Wood thrushes (*Hylocichla mustelina*), but also facilitated predator access to nests. The invasive plants leaf out earlier, and so are frequently chosen as nesting sites; the lack of thorns and lower nest height

Box 2. The Futi Corridor – Linking Tembe Elephant Park, South Africa to Maputo Elephant Reserve, Mozambique

Landscapes have naturally occurring borders that are not determined by political boundaries. Many political borders are freely crossed by animals to access the resources they need for survival, while others, such as many international borders, not only appear on maps, but are bounded by fences or other obstacles that fragment landscapes and ecosystems. These boundary markers may present an impenetrable barrier to species that can limit a population's access to needed resources or prevent migration and movement through a landscape. In these situations removal of border obstacles and creation of designated corridors to facilitate animal movement has sometimes proven to be a worthwhile solution.

The border between Mozambique and South Africa is an example of such a solution. A fence constructed along the border divided a population of elephants, the only indigenous population remaining on the coastal plain of Southern Mozambique and Kwa-Zulu Natal province in South Africa. These elephant traveled along the "Futi Corridor" (a seasonal river and marshland) that links Tembe Elephant Park in South Africa to Maputo Elephant Reserve in Mozambique.

With the end of political unrest an opportunity arose to assess the need for the fence and the potential for reunifying the elephant population. On June 22, 2000, the governments of Mozambique, Swaziland, and South Africa signed the Lubombo Transfrontier Trilateral Protocol, an agreement whose goal is to remove borders to support conservation. Scientists at the Conservation Ecology Research Unit (CERU) at the University of Pretoria spent three years tracking the movements of elephants along a section of the Mozambique/South Africa border (Van Aarde and Fairall, 2002). Using satellite radio tracking, they found that the populations still traveled the traditional routes they had used prior to installation of the fence. Examining the elephant population's movement patterns, and their impact on the landscape and interaction with humans, a series of recommendations to facilitate movement across the boundary while minimizing disruptions to the landscape and the human population were proposed. The recommendations included removing the border fences entirely, formal designation of the "corridor" as a protected area in Mozambique, and specific boundary parameters for the corridor. Plans are currently underway to implement the recommendations and establish a conservation area that will cross the political boundaries (Peace Parks, 2003).

Cross border conservation solutions have been used more and more frequently to facilitate conservation cooperation between countries around the world. Typically solutions like this are called Transfrontier Conservation Areas (TFCA's) or Transboundary Natural Resource Management solutions. These cross border efforts are instrumental in reunifying artificially-divided landscapes and can facilitate development of coordinated conservation practices. Other benefits include improved political relationships between countries, increased tourism opportunities, and the involvement of local communities in crafting conservation solutions that will provide direct local benefits. [For more details see the module on Transboundary Protected Areas].

Box 3. Identifying Species Vulnerable to Fragmentation

Knowing which species are most vulnerable is critical to understanding the impact of fragmentation. Behavioral patterns, resource needs, reproductive biology, and natural history can be used to identify species that are most vulnerable to fragmentation. Below is a list of characteristics that are typical of species more vulnerable to fragmentation (modified from Laurance and Bierregaard, 1997):

- Rare species with restricted distributions (Andersen et al., 1997)
- Rare species with small populations (Andersen et al., 1997)
- Species with large home ranges (Soulé et al., 1979; Newmark, 1987)
- Species that require heterogeneous landscapes
- Species that avoid matrix habitats (Warburton, 1997)
- Species with very specialized habitat requirements
- Species with limited dispersal abilities (Laurance, 1990, 1991)
- Species with low fecundity (Sieving and Karr, 1997)
- Species with variable population sizes using patchy resources
- Ground nesters vulnerable to medium-sized predators at edges (Bayne and Hobson 1997, 1998)
- Species vulnerable to hunting (Redford and Robinson, 1987)
- Species that are arboreal (canopy dwellers)
- Co-evolved species (e.g., plants with specific pollinators) (Gilbert, 1980)

of these shrubs in turn seems to aid predators in reaching the nests.

Fragmentation can also take an indirect toll on plants whose pollinators or seed dispersers are forced to navigate an increasingly fragmented landscape in search of their host plants (Aizen and Feinsinger, 1994). In western Australia, only small, isolated populations of the cone-bearing shrub, Good's banksia (*Banksia goodi*), remain, and many of these no longer reproduce because their pollinators have disappeared (Buchmann and Nabhan, 1997).

Fragmentation often alters animal behavior, due to changes in the environment or predator activity. For example, Hobson and Villard (1998) found that one bird, the American Redstart (*Setophaga ruticilla*) acted more aggressively when confronted with a model of a nest parasite—the Brown-headed Cowbird (*Molothrus ater*)—in fragmented landscapes than in unfragmented ones. This appears to be because Cowbirds are more common in fragmented areas, and are thus a greater threat to the Redstarts' breeding success.

Management of Fragmented Landscapes

Increasingly, conservation professionals are faced with managing fragmented landscapes. This challenge is complicated by the diverse responses of species to fragmentation and the complex decisions surrounding conservation of land. As with any conservation management plan, when examining a fragmented landscape, it is essential to identify clear goals. For example, for a wide-ranging species, such as the black bear (*Ursus americanus*), habitat connectivity is critical, so it is important to maintain a large unfragmented area; however, to conserve a rare species with specific habitat needs, it may be more important to preserve a specific place than a large area, so that smaller fragments are more valuable than larger fragments (Dale et al., 1994; Laurance and Bierregaard, 1997). While there are many different conservation strategies and options (Laurance and Gascon, 1997), here we will explore some of the strategies specially aimed at fragmented landscapes [For a detailed discussion of conservation management strategies see modules on Conservation Planning in and outside Protected Areas].

Recommendations

The following are important considerations to manage fragmented landscapes (Laurance and Gascon, 1997; Meffe and Carroll, 1997):

- *Conduct a landscape analysis* to determine where the big blocks of land suitable for protection exist and where potential connections among them lie.
- *Evaluate the landscape and each patch in a regional context.* If all surrounding landscapes are heavily fragmented and your focal landscape is not, its role in biodiversity conservation is important at a regional level. Protection and conservation action should be elevated accordingly. In contrast, if surrounding areas are largely unfragmented, fragmentation issues in your focal region may be less important.
- *Increase connectivity.* Examine different planning options to avoid or reduce fragmentation. Can roads be re-routed, alternative land uses be found, or protected areas be placed strategically? [See Box 1. Corridors and Connectivity]
- *Minimize edge effects.* Land managers often have some control over which land uses will be adjacent to one another. Land management policies can be established to ensure that a fragment's size and shape maximizes the effective area of protected land and reduces edge effects. Adequate buffer zones (where land use is compatible with species' needs) around protected land also minimize edge effects.
- *Remember small fragments.* They may not sustain jaguars or tapirs, but they still retain huge diversities of invertebrates, small vertebrates, plants, and perhaps rare or unique ecosystems and species.
- *Identify species most vulnerable to fragmentation.* It is important to identify those species most likely to be impacted by fragmentation and to consider them when designing management and monitoring plans. [See Box 3. Identifying Species Vulnerable to Fragmentation]

Terms of Use

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Glossary

Anadromous fish: fish that return from the sea to the rivers where they were born to breed (e.g. salmon).

Area-sensitive species: species that require large areas of continuous habitat and cannot survive in small patches.

Biome: a major biotic classification characterized by similar vegetation structure and climate, but not necessarily the same species.

Connectivity: the degree to which patches in a landscape are linked.

Corridors: linear strips of protected land.

Ecological release from competition: when competing species are removed, the resources they utilized become available to the persisting species.

Ecosystem: an assemblage of organisms and the physical environment in which it exchanges energy and matter.

Ecosystem loss: the disappearance of an assemblage of organisms and its physical environment such that it no longer functions.

Edge environments or ecotones: the transition between two different habitats.

Faunal relaxation: the selective disappearance of some species and replacement by more common species.

Fragmentation: the subdivision of a formerly contiguous landscape into smaller units.

Genetic drift: a random change in allele frequency in a small breeding population leading to a loss of genetic variation.

Habitat: there are two common usages of the term habitat. The first defines habitat as a species' use of the environment, while the second defines it as an attribute of the land and refers more broadly to habitat for an assemblage of species. For a discussion of different usages of habitat see Corsi et al., (2000). In this module we use habitat and "habitat type" to differentiate between the two common usages of the term.

Habitat degradation: the process where the quality of a species' habitat declines.

Habitat loss: the modification of an organism's environment to the extent that the qualities of the environment no longer support its survival.

Inbreeding depression: reduction in reproductive ability and survival rates as a result of breeding among related individuals.

Lentic: relating to or living in still or slow-moving water.

Lotic: relating to or living in swift-flowing water.

Matrix: the most common cover type in any given landscape. As it occupies the most area, it is the dominant feature of the landscape and usually the most connected cover type.

Meso predator release: as large predators disappear, the population of smaller predators often increases.

Patch: usually defined by its area, perimeter, shape, and composition, such as a land cover type (such as water, forest, or grassland), a soil type, or other variable.

Potential extent: the extent of coverage of a particular biome type, assuming there were no humans and based on current climatic conditions.

Trophic level: stage in a food chain or web leading from primary producers (lowest trophic level) through herbivores to primary and secondary carnivores (highest trophic level).

Assessing Threats in Conservation Planning and Management

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Assessing Threats in Conservation Planning and Management

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OBJECTIVES

- To develop a conceptual model for the threats faced by the Khakaborazi National Park, North Myanmar, based on a summary description of the Park (see below) and to identify objectives to reduce those threats (Level 1)
- To conduct a Threat Reduction Assessment of the project to measure project success (Level 2)
- To design a monitoring program for the project (Level 3)

BACKGROUND SITE INFORMATION

You are the scientific technical advisor for a collaborative project involving the Ministry of Forestry, Union of Myanmar, and an international non-governmental organization (NGO), the Nature Conservation Society. The Khakaborazi National Park was established in 1998 and spans 3,812 km^2; it is the second largest protected area in Myanmar. The northwestern boundary of the Park, or reserve, borders China (see Figure 2 below). High levels of species richness and endemism have led to the region being recognized as a conservation hotspot (Myers et al., 2000) and a globally outstanding terrestrial ecoregion (Wikramanayake et al., 2002). The region represents one of the few places in the Indo-Pacific region where potential exists for proactive conservation action to protect threatened species that are rare or declining in neighboring countries.

The Park consists primarily of large areas of subtropical broadleaved forests but also includes small patches of temperate broadleaved forests and sub-alpine conifer forests. The region contains the headwaters of the country's most important river system, the Ayeyarwady, which drains vast expanses of agricultural lands and helps sustain extensive rice production areas in this predominantly agrarian economy. Forest areas lying south of the Park border and demarcated by the Nam-Tamai River have been proposed for designation as a buffer zone area comprising 690 km^2. There are 13 villages with a total population of 2,000 people within the Park itself and 36 villages with a population of approximately 8,400 people within the buffer zone of the Park. The majority of the population is concentrated within five villages: Makhungam, Pannandin, Gushin, Tazundam, and Tasuhtu. Residents belong to two major ethnic groups: Lisus and Rawans.

Village residents pursue various occupations including shifting and permanent cultivation, livestock raising, hunting for subsistence and trade, and honey and medicinal plant trading. Villagers harvest timber and non-timber forest products (NTFPs) for use in their homes and for sale in local markets. The Lisus are professional hunters and undertake long hunting expeditions to remote areas throughout the year. Most hunting by the Rawans occurs during the winter months (November-March) and coincides with the growing season for agricultural crops. Hunting for trade is suspected to have resulted in the local extirpation of mammals such as the elephant (*Elephas maximus*), tiger (*Panthera tigris*), rhinoceros (*Dicerorhinus sumatrensis*) and gaur (*Bos gaurus*).

Funding for the project is from a large international environmental NGO and a private philanthropic foundation. The project is currently scheduled to last for five years. Core NGO and Government staff members involved with this project include the NGO executive director, the Park director, the agronomist, the ecologist, and the project community enterprise specialist. The goal of this project is to conserve the primary forest and wildlife in the Khakaborazi National Park, which is globally recognized for its rare and endemic flora and fauna.

The greatest threats to wildlife in the core area of the reserve are hunting for trade, habitat destruction through shifting cultivation, a proposed mining concession, and over-extraction of forest products. Hunting for trade is one of several sources of cash income for some of the village residents who often trade wildlife in exchange for basic household items or cash. However, many heavily hunted species are gradually being locally extirpated due to trade that occurs across the porous northern boundary of the reserve and the few villagers who are actually dependent on wildlife as a source of protein are finding it increasingly difficult to obtain what they require. Traders from across the border routinely visit the villages and reap a much larger share of the profits than the villagers who actually hunt the species. The project needs to take swift and effective action to address this widespread problem.

Shifting cultivation by landless villagers in easily accessible, low elevation regions of the buffer zone and core area has resulted in degraded forest patches, and there is some indication to suggest that the problem is escalating due to population growth. There is a large mining concession proposed within two years in the core area of the Park by the Ministry of Natural Resources, to be leased to an international mining company for a period of 20 years. If the mining concession is approved, the Ministry of Forestry will be forced to redraw the boundaries of the reserve, significantly reducing the core area of the Park. Many stakeholders, including the villagers, are against the mining concession. Over-harvesting of non-timber forest products occurs primarily within the buffer zone and within a 10 km radius of the villages. Anecdotal evidence seems to indicate that the number of people involved in this activity is on the decline due to reduced availability of resources.

Lack of awareness of wildlife and forest laws, insufficient opportunities to pursue more sustainable sources of livelihood, lack of systematic land-use planning, and inappropriate development policies all negatively influence the conservation of natural resources of the Khakaborazi National Park.

PROCEDURES

Instructions for Students

LEVEL 1

Objective: to Develop a Conceptual Model for the Khakaborazi National Park Identifying Objectives to Address Threats

A conceptual model in this context is a simple, graphical tool used to design, manage, and monitor conservation projects. It is used to identify threats affecting biodiversity at a designated site and the conservation actions needed to address those threats. It has three main components:

1) The **conservation target,** i.e. the target condition (such as biodiversity) that the project ultimately would like to influence.
2) Causal chains of *direct* and *indirect* **threats** affecting the conservation target. Direct threats are factors that immediately affect the target condition or physically cause its destruction, and include habitat fragmentation, invasive species, pollution, overexploitation, and global climate change. Indirect threats are defined as factors that underlie or lead to the direct threats (see module *Threats to Biodiversity: An Overview*).
3) A description of the **conservation actions** (**objectives** and **activities**) that project managers can use to counter the threats to their conservation target. (See Figure 1 below).

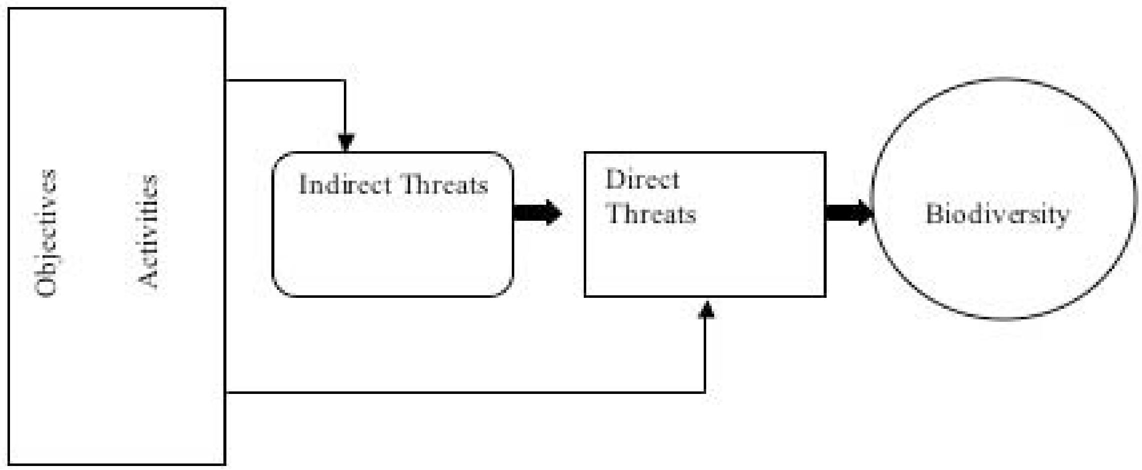
Using the data provided in the background information for the site, develop a graphic conceptual model identifying the **conservation target**, **indirect and direct threats**, and at least one **objective** and one **activity** to reduce each threat. Objectives differ from activities in that activities are specific actions or tasks undertaken by project staff designed to reach each of the project's objectives.

In developing objectives for the project, evaluate whether these objectives meet the following criteria.

A good **objective** meets the following criteria:

- *Impact oriented*. Represents desired changes in critical threat factors that affect the project goal.
- *Measurable.* Definable in relation to some standard scale (numbers, percentages, fractions, or all/nothing states).

Figure 1: Conceptual model



- *Time limited*. Achievable within a specific period of time.
- *Specific*. Clearly defined so that all people involved in the project have the same understanding of what the terms in the objective mean.
- *Practical*. Achievable and appropriate within the context of the project site.

A good **activity** meets the following criteria:

- *Linked*. Directly related to achieving a specific objective.
- *Focused*. Outlines specific tasks that need to be carried out.
- *Feasible*. Accomplishable in light of the project's resources and constraints.
- *Appropriate*. Acceptable to and fitting within site-specific cultural, social, and biological norms.

It can take a bit of thinking to decide if something is an objective, activity, or neither one. In the following table, identify the item listed in the first column (Example) as being either an objective, an activity, or neither, and indicate why in the last column (Explanation).

Example	Objective, Activity, or Neither	Explanation
1. To promote community well-being and health in the area surrounding Khakaborazi National Park.		
2. To reduce the amount of illegal hunting in the reserve by 30 percent in two years.		
3. Within 3 years, support the Department of Parks in its efforts to enforce hunting regulations within the Khakaborazi National Park.		
4. By the end of the project household income for all families participating in non-timber forest product harvesting enterprises has increased by at least 20 percent.		

LEVEL 2

Objective: To Develop a Threat Reduction Assessment for the Project

One way to measure conservation success is through the threat reduction assessment (TRA) approach described in Salafsky and Margoluis (1999). This approach monitors threats to conservation targets rather than directly monitoring the conservation targets; e.g. through this approach one would monitor harvest rates for hardwoods rather than the size and status of hardwood populations. Assessment of the progress in reducing threats provides a framework for measuring conservation success.

An index known as a **threat reduction index** is used to implement the TRA approach. The index is designed to identify threats, rank them according to their relative importance, and assess progress in reducing each of them. The information is then pooled to obtain an estimation of actual threat reduction. Threats are ranked on the basis of three criteria: area, intensity, and urgency. Area refers to the percentage of the habitat(s) in the site that the threat will affect: will it affect all of the habitat(s) at the site or just a small part? Intensity refers to the impact of the threat on a smaller scale: within the overall area, will the threat completely destroy the habitat(s) or will it cause only minor changes? Urgency refers to the immediacy of the threat: will the threat occur tomorrow or in 25 years?

In Khakaborazi National Park, hunting for trade declined to approximately half the original level two years following project initiation. The area affected by shifting cultivation in the core zone has increased by 10% and the proposal for the mining concession has stalled due to a number of reasons, including successful advocacy by the project and disagreements between the Government and the international mining company. The over-harvesting of forest products has declined by 30%.

Using this information, together with the background site data, conduct a Threat Reduction Assessment to determine if the project in Khakaborazi National Park is succeeding.

Example of a Threat Reduction Assessment Exercise

The Research and Conservation Foundation in Papua New Guinea worked with the Wildlife Conservation Society to implement research tourism and handicraft enterprises with the communities of Crater Mountain Wildlife Management Area (CMWMA) in the highlands of Papua New Guinea. Table 1 below shows results of the application of the procedure to the Crater Mountain Project.

Table 1: Sample calculation of threat reduction assessment (TRA) index based on data drawn from an interview with field staff about the Haia site (1994-1997 assessment period) at the Crater Mountain Wildlife Management Area Project in Papua New Guinea

Direct threat (1)	Area ranking (2)	Intensity ranking (3)	Urgency ranking (4)	Total ranking (5)	Threat met (%) (6)	Raw TRA index score (7)	Final TRA (8)
Hunting (subsistence)	5	3	4	12	15	1.8	
Logging (corporate)	2	5	1	8	50	4.0	
Expansion of gardens	4	1	5	10	5	0.5	
Hunting (market)	3	2	3	8	0	0.0	
Mining (commercial)	1	4	2	7	100	7.0	
Totals	**15**	**15**	**15**	**45**		**13.3**	**30%**

Calculation of the TRA index in the Crater Mountain example above showed that there was a 30% reduction in total threats, primarily by reducing the threats posed by corporate logging and commercial mining.

In order to do this, you will need to follow these steps:

(1) *Develop a list of all direct threats to the biodiversity at the project site present at the start date.* Direct threats (Table 1, column 1) are those that immediately affect the biodiversity of the site. Indirect threats (e.g., poverty) are those that cause direct threats (e.g., logging) and should not be included in the list. It is advisable, however, to group together direct threats that come from different proximate or ultimate causes (e.g., hunting for subsistence or hunting for market sale) or that are presented by different stakeholders (e.g., local people clearing forest for agricultural gardens versus external companies clearing forest to produce timber for commercial sale).

(2) *Rank each threat based on three criteria: area, intensity, and urgency.* Count the total number of threats and assign this number (n) to the highest ranking threat in each category (Table 1, columns 2-4). For example, if there are 5 threats and subsistence hunting is the most serious threat, as in the example above, then its rank is 5. Assign the next highest-ranked threat in each category the score n – 1. Continue ranking the threats until you get to 1, which is assigned to the lowest-ranked threat. Tip: it can be helpful to write all the threats on separate slips of paper, which can then be moved up or down relative to one another to create the rankings.

(3) *Add up the score across the three criteria.* Add the three rankings for each threat together to get the total ranking (Table 1, column 5). Assign an equal weight to each of these columns. (If desired, these columns could be weighted, but this would complicate calculation of the index.)

(4) *Determine the degree to which each threat has been dealt with.* At the start of the project, for each threat identified, it is necessary to define what completely (100%) eliminating this threat would look like. For example, 100% reduction of the threats of:

- Subsistence hunting (harvesting of birds and mammals by local people for their own consumption) might involve harvesting animals on a sustainable basis through setting up and implementing hunting regulations;
- Corporate logging (timber harvesting conducted by large multinational firms) might involve eliminating logging and any plans for logging in the boundaries of the management unit;
- Expansion of gardens (cutting primary forest to make subsistence agricultural plots) would involve eliminating expansion of gardens into areas of primary forest;

- Market hunting (harvesting of selected bird and mammal species that are commercial commodities) might involve harvesting animals on a sustainable basis through setting up and implementing hunting regulation;
- Commercial mining (mineral extraction conducted by large, multinational firms) might involve eliminating mining and plans for mining in the boundaries of the management unit.

At the end date of the assessment period, and subsequent to defining 100% reduction for each threat, work with the project team to determine the degree to which each threat has been addressed, based on definition of 100% threat reduction described above. These assessments can be made either quantitatively (e.g. area of forest that has not been clear-cut by logging firms, or reduction in numbers of animals hunted) or qualitatively (e.g., ranking of intensity of clearing for agriculture on a scale 1-5, or assessing local expert opinion on the level of hunting), depending on the type of threat and the data available. In all cases, the reduction in threat should be expressed as the percent change in the original threat identified at the start of the project (Table 1, column 6).

(5) *Calculate the raw score for each threat*. Multiply the total ranking by the percentage calculated in step 5 to get the raw score for each threat (Table 1, column 7).

(6) *Calculate the final total threat reduction index score.* Add up the raw scores for all threats (13.3 in Table 1), divide by the sum of the total rankings (e.g., 45 in Table 1), and multiply by 100 to get the final threat reduction assessment index (30%) for the project (Table 1, column 8).

Calculation of the TRA index in the Crater Mountain example above showed that there was a 30% reduction in total threats, primarily by reducing the threats posed by corporate logging and commercial mining. A key lesson learned from the analysis was that it is generally fairly easy to define and assess success in meeting external threats such as corporate logging or mining. It is much harder to define and assess success in meeting internal threats such as over-hunting of wildlife or expansion of subsistence food gardens, especially if the information for evaluating the threat comes only from the local people. What are the key lessons that you can draw from the TRA for the Khakaborazi National Park?

LEVEL 3

Objective: To Design a Monitoring Plan for the Project

In a conservation project, an approach to measuring management effectiveness is to either monitor the status of threats themselves or monitor the ecological integrity of the conservation targets or do a combination of the two approaches. The two broad categories may be summarized as:

1. Assessment of the status and impacts of threats
2. Measurement of the ecological integrity of conservation targets

For the first category, the measurement of threat status as an indicator of management effectiveness, the question addressed is as follows: are the most critical threats that confront biological resources at a park changing in their severity or geographic scope as a result of conservation strategies (or lack thereof)? For example, has wildlife poaching declined as a result of efforts to develop and improve contained domestic animal husbandry as a protein source for local communities?

For the second category, measuring ecological integrity as an indicator of management effectiveness, the question becomes: do the ecological systems, communities, and species that are the focus of conservation efforts occur with sufficient size, with appropriately functioning ecological processes, and with sufficiently natural composition, structure, and function to persist over the long term? For example, are populations of mammals and birds declining at a slower rate, or growing, as a result of alternative protein production activities?

This stage of the exercise project aims to address all the major threats to the Khakaborazi National Park as described in the section titled "Background Information" above. You need to develop a Monitoring Plan that will help you and your team determine whether the strategies you have chosen to counter the threats are effective and if your project is succeeding. You can choose to either focus on monitoring biological/ecological indicators (e.g. population status of hunted wildlife species) or the threats themselves (e.g. hunting). An important step in the development of a monitoring program is to identify key indicators such as land-use change, fluctuations in species populations, ecotourism visitor impacts, etc. that are relatively easy and cost-effective to monitor through the duration of the project. Refer to Boxes 1 and 2 below to help you identify monitoring strategies and indicators that will help determine project success.

(1) For each objective and activity that you have identified in Level 1 above, identify one or more monitoring strategies that you feel will help measure project success in reducing that particular threat.

(2) For each monitoring strategy, identify what (i.e. indicators) and how (i.e. methods) you will monitor.

(3) The monitoring strategies you have chosen will fall into one of two broad categories. The strategy will focus on biological monitoring as in the monitoring strategy 2 above (i.e. measuring the ecological integrity of targets such as forest area, status of wildlife populations, etc.) or threat monitoring as in monitoring strategy 1 above (i.e. measuring

the status of threats such as fires, commercial logging, etc.). Classify the strategies you have chosen into one of the two categories and briefly tabulate the major advantages and disadvantages of the two types of monitoring systems. Are there other monitoring methods you can think of?

Box 1. For example

Threat: Commercial logging within the core area of the reserve

Objective: To stop all timber extraction in the core area of the reserve by the end of the third year of the project

Monitoring strategy 1: Determine changes over time in a number of active logging concessions in the reserve.
Indicator: Number of active concessions in reserve core area.
Method: Periodic review of updated records from the Ministry of Natural Resources regarding the number and duration of offical concessions.

Monitoring strategy 2: Measure changes over time in area of core forest zone affected by logging.
Indicator: Area (ha) of undisturbed and disurbed core reserve area.
Method: GIS and land-use mapping.

Box 2. Threat impact monitoring

Variable monitored	Monitoring parameters	Reference
Land-use changes as an indicator of protected area integrity	Land use pressure (land-clearing, logging, hunting, grazing, fire)	Bruner et al., 2001; Jepson et al., 2002
Ecotourism visitor impacts in protected areas	Trails and recreational site impacts, behavioral parameters target species	Farrell and Marion, 2001; Kinnaird and O'Brien, 1996
Species persistence within individual protected areas	Mortality causes (incl. effects of poaching on mortality) and rates for Eurasian badgers in relation to edge effeects	Revilla et al., 2001
Habitat fragmentation	Degree of fragmentation (distribution and intensity); loss of primary forest, structural classification based on radar data	Saatchi et al., 2001
Harvest of plant resources	Effects of harvesting on distribution, abundance, population structure, population dynamics of harvested NTFPs	Hall and Bawa, 1993; Godoy and Bawa, 1993
Impact of hunting and trade on a single species	Type and number of wildlife species captured and traded; offtake	Johnson et al., 2004
Ecological degradation in protected areas	Rate of change in forest cover and habitat (Giant Panda)	Liu et al., 2001

Figure 2: Location map of Khakaborazi National Park

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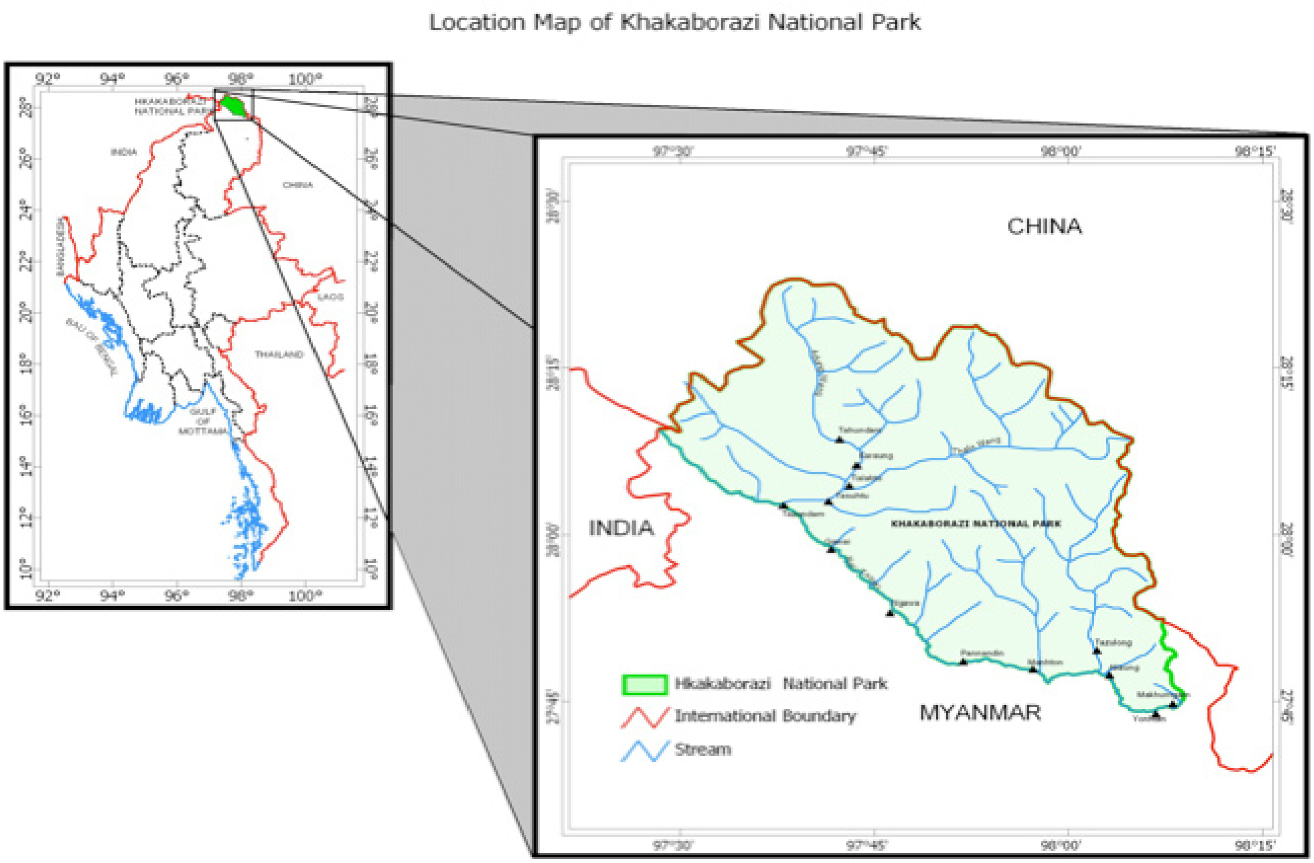

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Forest Fragmentation and its Effects on Biological Diversity: A Mapping Exercise

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Forest Fragmentation and its Effects on Biological Diversity: A Mapping Exercise

James Gibbs

GOALS

This exercise has two goals. The first is to permit you to explore through a mapping exercise what happens to a forested landscape as it undergoes the fragmentation process. The second is to let you predict what will happen to the biota residing within the landscape as a result of these changes. The fundamental question we address is: can landscapes be fragmented in such a way that permits humans and biological diversity to coexist?

OVERVIEW

The first part of the exercise involves measuring changes in a forested landscape as it is fragmented. You begin with a blank grid that represents an undisturbed landscape dominated by forest. Much of the forest is on the upland but some also occurs in wetlands connected by streams that are themselves surrounded by gallery forest. Both wetland forest and gallery forest are considered "seasonally inundated forest" and are indicated on the map by wetland symbols.

Starting with the blank grid, you will mark grid squares in a progression that mimics fragmentation of the landscape associated with colonization by humans, first by adding a major road and the cleared lands associated with it, and then adding secondary roads and tertiary roads and the cleared lands associated with them. "Filled" grid squares will represent areas cleared of forest and converted for agricultural purposes whereas "cross hatched" grid squares will represent edge zones of remaining forest that are directly adjacent to cleared areas. You will then repeat this fragmentation process while invoking some simple land use guidelines to examine how they might influence the outcome in terms of structure of the landscape and the biodiversity within it. You end up with three landscapes to compare: (1) the original landscape, (2) the landscape subjected to uncontrolled fragmentation, and (3) the landscape subject to fragmentation guided by some simple land use regulations and alternatives.

The second part of the exercise enables you to predict what will happen to the biota residing within the landscape as a result of its fragmentation. For each of your mapped scenarios for the same landscape, you will calculate some key biological parameters to make predictions about the state of biological diversity and ecosystem function within the landscape. You will examine how changes in the landscape affect: (1) ecosystem diversity of the landscape, (2) species diversity within the landscape, and (3) ecosystem function in terms of carbon sequestration within the ecosystems present. Advanced students may also want to attempt the remaining steps, which address: (4) population viability of a large herding mammal, (5) foraging energetics of wide-ranging birds, and (6) effective population size and genetic drift in a canopy tree. By contrasting these biological indicators in the three landscapes you generate, you will get a good sense of how fragmentation affects biodiversity and how we can mitigate some of the negative effects through planning and incentives.

PART I

The Forest Fragmentation Process

Becoming Familiar With the Basic Map

First, get oriented to the basic map by noting the cardinal directions. Which way is north? South? East and west? Second, familiarize yourself with the map's scale. Each grid square is 100 m on a side. What is the area of each grid square? What is the width and length of the study landscape? What is the total area of the landscape (in ha and km^2)? If you move horizontally from one grid square to the next, what distance have you moved? If you move diagonally, how far have you moved? Now look at the different cover types. Can you recognize the inundated (wetland and gallery) forests? The upland forests? The streams and other watercourses?

Scenario I: The original landscape with natural small, scattered disturbances and its human population

Scattered disturbances are typical even within the original, unfragmented landscape. These might be due to lightning strikes that have created small openings. Many of these may also have been created by humans who have constructed small, shifting garden plots in certain areas or lit fires in others to generate second growth and attract game. These disturbance patches usually don't comprise a large portion of the landscape (perhaps up to 2% of the area) and are generally well dispersed. To mimic this situation, randomly choose 2% of the grid squares and convert them to open habitats (filled grid squares) and change the grid squares surrounding open habitats to edge habitats (cross-hatched grid squares).

What is the human population being supported within the landscape? Assume that each family (average of five people per family) needs exclusive access to 3 hectares of cleared land for cultivation to meet their needs or 50 hectares of forestland (upland or inundated and not necessarily contiguous) for extraction of natural products and hunting. Often people combine both cultivation and harvest of wild products but we will consider a simple division of livelihoods in this case.

Scenario II: The landscape fragmented in an uncontrolled manner
Starting with a blank map of the original landscape, add a road dissecting the region. This road might be the end result of exploration of a remote area for oil or gas or the result of a government effort to access a frontier zone. To make this road, simply draw a heavy line along an east-west axis through the middle of one of the central rows of grid squares. The road width is negligible and can be ignored but it provides immediate access to the grid squares traversed and those immediately adjacent to them (150 m back from the road). These are converted to agriculture. Therefore, fill in all traversed and adjacent grid squares - three rows total.

Note that this initial dissection of the forest also changes the forest that is adjacent to the converted lands into edge habitat. Consider that ecologically important edge effects can extend at least 100 m into a stand, so cross-hatch all the forested grid squares adjacent to cleared land to indicate where forest edge has been created.

Now add more roads. These are the kinds of roads created by people who follow the first major road and now seek to colonize the area and convert more of the forest for agriculture and other uses. Add two such roads by drawing dark lines perpendicular to the initial road that cross it at about 450 m and 1450 m along its length. Extend the secondary roads in both directions right across the landscape. Repeat the process of demarking converted lands 150 m from the roadsides and then the edge habitats adjacent to them.

Calculate the human population supported within the landscape.

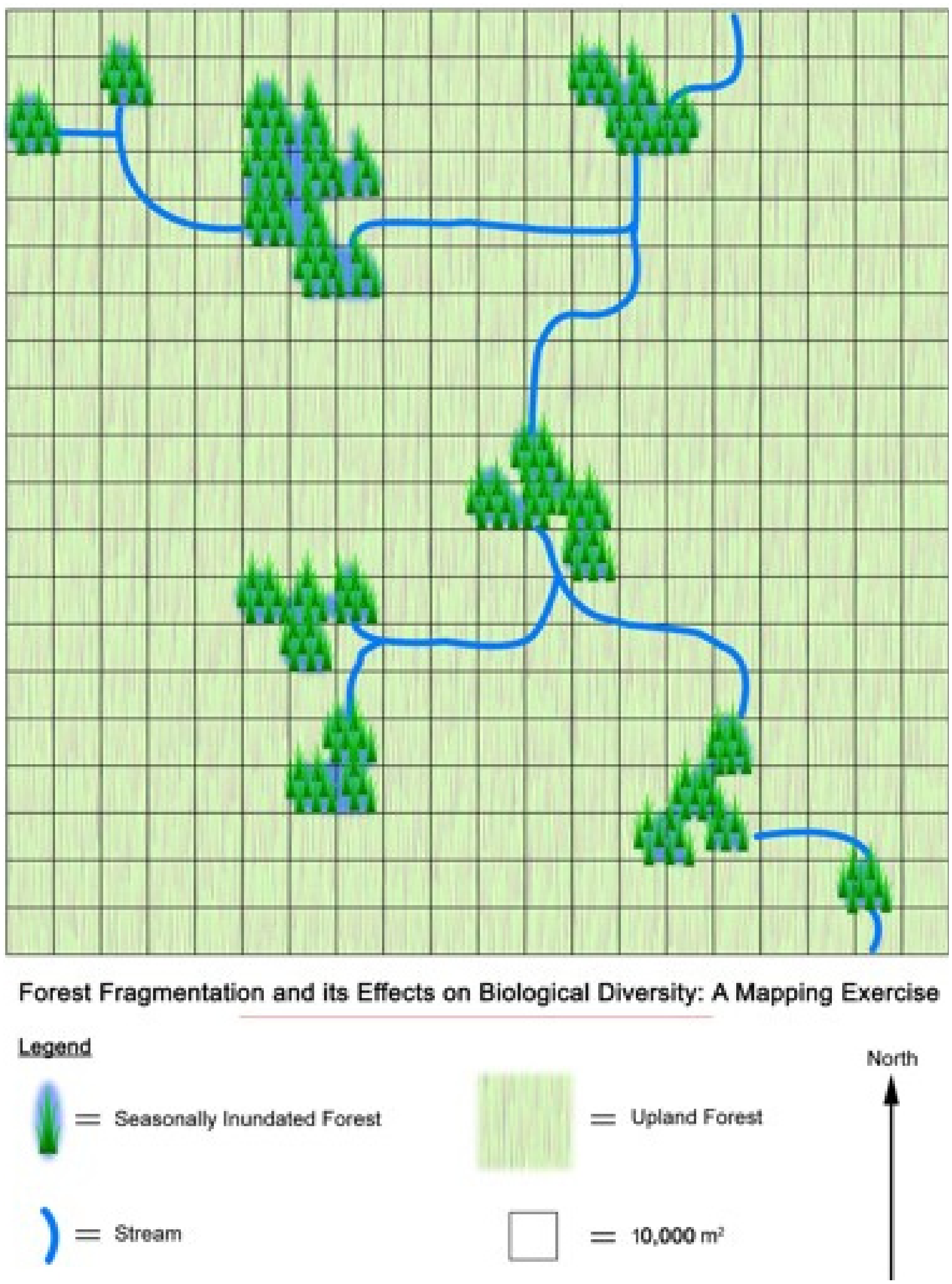
Scenario III. The landscape fragmented following some simple land use guidelines
Starting with a clean map, add roads and cleared lands as you did in Scenario II, with the objective of generating sufficient resources for a comparable number people, but place the roads in any configuration you want that satisfies these simple land use guidelines and land use alternatives (adapted in part from Laurance and Gascon, 1997):

- Triple the production rates on cultivated land through provision of fertilizer and perhaps alternative crops so that local people now need to clear only a third as much forest to meet their needs. Note that under the land use alternatives scenario, however, each family can meet its needs on just one hectare of cultivated land because productivity has been tripled. In other words, now you only convert the lands up to 50 m from roadsides, so fill in only the blocks directly intersected by the road.
- Prohibit forest clearing of any habitat block that supports a watercourse. Note that roads can traverse watercourses but the forest blocks that include water courses are not cleared.

- Protect all rare ecosystems -- no conversion of inundated forests.
- Allocate half of the landscape to production purposes and human use while allocating the other half to reserve status.

Recalculate the human population supported within the landscape.

Figure 1. Map for Exercise.



PART II

Biological Implications of Fragmentation Scenarios

Step 1. Landscape Analysis and Ecosystem Diversity

For each of the maps that you produce from the three fragmentation scenarios above, tally the area of the landscape that is upland forest interior, upland forest edge, inundated forest interior, inundated forest edge, and land converted from forest to agriculture. Note that riparian zones of the watercourses are natural "edges" or ecotones, but we are concerned here with forest edges adjacent to open habitats. Calculate the fraction of the landscape composed of each habitat. Last, estimate ecosystem diversity within each of these landscapes using the Shannon-Weiner index of diversity, which is

$$-\sum pi * \log(pi),$$

where pi = the fraction of the landscape represented by ecosystem$_i$. For example, if interior forest occupied 900 of the total 1000 grid squares and inundated forest occupied the rest of the landscape, then Simpson's index of diversity would = (0.9*log(0.9))+(0.1*log(0.1)). Your calculations will be similar but made across all ecosystem types.

Step 2: Changes in Ecosystem Function – Carbon Sequestration

Based on the estimates of Laurance et al. (1998) for Amazonian moist forest near Manaus, Brazil, forest biomass averages 300 tons/ha with carbon comprising 50% of that amount. Forest clearing commits 95% of forest biomass to carbon emissions from burning and decay with 5% remaining as relict living trees in pastures or inert as charcoal. Forest edges lose 10% of their biomass as mortality of trees is higher on the edges. Do not distinguish inundated from upland forests for this exercise. Based on these relationships, estimate the tons of carbon sequestered by the landscape in above-ground woody biomass under the three different landscape scenarios.

Step 3: Changes in Faunal Diversity

Estimate the faunal diversity of an average habitat block within the landscape under the different scenarios of fragmentation (undisturbed, uncontrolled fragmentation, fragmentation with some land use guidelines and alternatives). This can be done with information on birds, mammals, frogs, and ants gathered by Gascon et al. (1999). These researchers worked over several decades to determine which species near Manaus, Brazil, primarily used forest interior, forest edge, and "matrix" or open lands near fragments. Note that some of the forest species listed below use the matrix but still rely on the primary forests.

Approximating from the Gascon et al. (1999) report (Figures 2 & 3), for birds there are locally some 123 species, 31 of which use the matrix (converted lands) versus 92 that use the forest edge and 92 that use forest interior. Note that no birds were restricted to the forest interior, so the same 92 occur in both edge and interior areas. For frogs, there are 62 species, 16 of which use only the matrix, 52 of which occur in the forest interior, and 51 of which use the forest edge. Of 15 mammals in the area, 4 use the matrix only, 15 use the forest interior, and 10 use the forest edge. For the 127 ant species, 32 use the matrix only, 104 use the primary forest, and 44 use the forest edge. Do not distinguish inundated from upland forests for this exercise.

Now calculate the average diversity per hectare for each of these faunal groups. To do so, for each landscape multiply the number of hectares of each habitat type by the expected diversity within it. Next sum these values across habitat types. Last, divide by the sum of the weights, which is the same as the total area of the landscape. For example, if the landscape was composed of 1000 grid squares, of which 500 were primary forest, 250 were forest edge, and 250 were matrix, then ant diversity on average in that landscape would = ((500*104)+(250*44)+(250*32))/100. This "weighted average" will indicate how many species are likely to occur, on average, per hectare in each landscape.

[Optional exercises for advanced students]

Step 4: Population Viability of a Herding Species With a Large Home-Range

Assume that one km^2 of forest (interior and edge) can support five white-lipped peccaries and that these animals live in herds (Fragoso, 1998) that roam in a fairly predictable fashion about the landscape. Also assume that the peccaries are reluctant to cross roads and cleared areas because they will be shot and therefore restrict their movements to individual forest remnants. Therefore, forest blocks support isolated populations.

What is the total peccary population among all the remaining viable populations? To answer this, you will first have to tackle the following questions: How many peccaries can each of the remaining forest patches support? What fraction of patches contains both the upland and wetland forest that are required to meet the annual needs of these animals during the wet and dry seasons? Note that if both wetland and upland forest are not available within a forest patch, then a population cannot be supported.

Step 5: Mobile Species and Foraging Energetics

Let's consider a wide-ranging, large-bodied frugivorous bird that must visit many sites every day to harvest newly ripened fruit. A hornbill, quetzal, or large parrot are good examples. Let's assume the tree species whose fruits it needs occur only in inundated forests, that is, in the highly clumped distributions that are typical of many tropical trees. How far must these birds travel on average each day to meet their daily needs? Assume that a pair of these birds must visit five such patches (one hectare blocks of inundated forest) each day.

To answer these questions, first trace the shortest path possible between all patches of inundated forest in the landscape. Start with an isolated patch in one of the corners of the landscape. It's virtually impossible to find the exact shortest path so just try to link all patches together as might a foraging bird that was trying to save energy flying between all the patches. As you move to the next nearest patch of inundated forest not yet visited, sum up the distance of each sequential move. The total distance traveled divided by the total number of patches visited equals the average cost of accessing a foraging site. Recall that the birds must visit five patches per day to meet their needs.

Step 6: Genetic Diversity in a Canopy Tree

Consider a rare tree species with mature individuals distributed evenly through the upland forest at a density of only one per hectare. A good example is *Pithecellobium elegans* (Chase et al., 1996; Hall et al., 1996). Any trees within 250 m of any other trees represent part of the same breeding population (can exchange gene flow). More distant individuals are unable to exchange pollen effectively and are therefore considered to be members of a different population. First, mark the individuals linked through potential gene flow by drawing a line that includes all collections of individuals within 500 m of another individual.

Next, assuming that the genetically effective population size in this species equals the census population size (only breeding adults in this long-lived species are considered), what average fraction of heterozygosity will be lost over the next 100 generations from each of the remaining breeding populations? Recall that the formula for estimating the amount of genetic variation (heterozygosity) in a population of size Ne retained after t generations = $[1 - (1/(2*Ne))]t$

Repeat these calculations for each *Pithecellobium elegans* population under each of the three landscape fragmentation scenarios. What is the least amount of genetic diversity lost by any single population under each scenario?

PART III

Synthesis

Construct a table that summarizes, for each of the three fragmentation scenarios, the (1) human population supported in the landscape, (2) characteristics of the landscape (fraction of land in different habitat types), (3) estimates for the key biological indicators:

fraction of land in different habitat types, ecosystem diversity, carbon emissions from the landscape, average faunal diversity per habitat block, population size and viability for white-lipped peccaries, foraging energetics for the frugivorous bird, and genetic diversity in the tree *Pithecellobium elegans*. To indicate how sensitive each parameter is to the fragmentation process, calculate the proportional change in each parameter relative to its value in the original landscape (Scenario I). Can you conclude that biodiversity and substantial human populations can co-exist despite fragmentation to the landscape? What social incentives and political means are available to actually achieve a landscape like that in scenario III?

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Biodiversity Conservation and Integrated Conservation and Development Projects (ICDPs)

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OBJECTIVE

This exercise is based on two case studies of project sites in two fictitious countries, Talamanca and Somoza in Central America. Following is a detailed description of the site conditions and ICDP designs. The donor organization for both the ICDPs is the same. You are hired by this organization as an external consultant to review, analyze, and predict the potential success or failure of the ICDPs and advise the relevant management agencies at both sites on critical issues regarding sustainability that need to be considered prior to moving ahead with actual implementation.

SITE 1

Description

Sirena National Park (SNP) and the surrounding conservation areas on the Madrigal Peninsula in Talamanca represent the largest remaining lowland rainforest on the Pacific coast of Central America. Despite the fact that nearly 85% of the peninsula (170,000 hectares) is legally protected in some form, rapid land-use changes and forest clearing threaten the biological integrity of the entire area. Despite the existing regulations, the deforestation rate for the whole peninsula (as determined last year) was 4.7 per cent. The Sirena National park (42,000ha) contains over one-quarter of all the tree species known to exist in the country and an incredibly rich fauna. The Park is surrounded by three conservation areas that include a biological reserve (1400ha), a wildlife refuge (3200ha) and a large forest reserve known the Rio Dulce Forest Reserve (RDFR) (85,000ha). Given its size, the RDFR is of substantial ecological importance since Sirena National Park alone is not sufficiently large to protect many of the species inside its boundaries. The management authority for the park and surrounding areas including the Rio Dulce Forest Reserve is vested in a regional Government conservation authority. However, the agency lacks a clear mandate in terms of its authority to manage the area given conflicts with other Government agencies.

Large parts of the peninsula including the RDFR continue to be deforested. The regional Government conservation agency has lacked sufficient funds to enable effective management. The legal status of the park is weak and the lack of Government funding and political will to support SNP translates to inadequate protection. Overall, the situation is extremely complex, constantly evolving with no comprehensive information available on the level of resource use within the park and buffer zone or the complete socio-economic, biological, and institutional context.

Social and Political Context/Land and Resource Tenure Issues

The social and political context on the Madrigal Peninsula, particularly in and around Sirena Park, is complex and conflictive. Rapid land-use changes on the peninsula brought about by flawed land-tenure policies, road construction, and other infrastructure development, combined with greatly increased pressures due to the recent economic situation in the country, are placing serious pressures on the park. Opportunities for sustainable resource extraction, such as forestry or agriculture, are limited, since most of the peninsula is hilly and susceptible to rapid erosion once forests are cleared. There has been virtually no coordination of the many institutions involved in the Madrigal Peninsula, particularly in the SNP and the surrounding RDFR. Consequently, there is no clear understanding of the social and economic context for the constantly changing conditions at the site.

Threats

The northern section of SNP is threatened largely from hunting and fishing and the southern portion is threatened by agricultural encroachment and mining. Little empirical information is available on resource use within Sirena Park. All extractive or consumptive use of resources within the park is illegal. Illegal activities within SNP do not appear to be large scale; the threats are from the aggregate of many small-scale activities, particularly mining and hunting. However, given the declining economic situation in the country, pressures on SNP, particularly hunting and mining, will intensify.

Indirect threats with potentially greater impact include:

- Deforestation and hunting in the surrounding Rio Dulce Forest Reserve that are impelled by socio-economic problems, particularly poverty
- Regional land-use change and development on the peninsula
- Lack of political will to manage the SNP and surrounding conservation areas including the RDFR

The more immediate threat to SNP is due to its small size because the survival of many of SNP's species depends upon an intact Rio Dulce Forest Reserve as a functioning buffer zone. Logging, clearing, and conflicts over land titles in the RDFR are serious and urgent threats to the integrity of SNP. If logging and clearing continue in the RDFR, SNP will become an ecological island. Furthermore, current estimates indicate that at present rates of clearing, the Rio Dulce Forest Reserve will be substantially cleared over the next 5 years. There is growing real estate speculation and land subdivision for sale to foreigners in areas surrounding the SNP including the RDFR. Lack of coherent and consistent policies, especially regarding land and resource tenure and deforestation, are root causes underlying threats. Inappropriate forest policy and perverse incentives promote deforestation in the buffer zone area. The legal system is unable to respond to deforestation, one of the principle threats to SNP.

Tourism has become the country's second-greatest source of foreign income. While tourism to the SNP has increased significantly, most tourists do not come in contact with the communities near the SNP and within the RDFR. Instead, they go to a series of lodges on the north and eastern side of the peninsula and enter the park only for a day. Tourism may actually pose a threat to the biological integrity of the park.

Community Participation and Attitudes Towards SNP

There are a large number of diverse communities resident within the RDFR and about 300 squatter families within the SNP. A tumultuous history of migration and land settlement in the peninsula has led to extremely strained relations between communities living in and around the SNP and the regional government conservation authority. The ICDP that is being planned is focused almost entirely within the RDFR on the assumption that the squatter communities within the SNP will be resettled outside the park in the near future. The resettlement process is currently stalled due to the lack of available land outside the reserve for resettlement. However, the agency has tried to engage both sets of communities (those within the SNP and RDFR) in dialogue to discuss the design of the ICDP described below. Given that most of the ICDP activities are focused in the RDFR, communities within the SNP are antagonistic toward the process. Previously, communities inside SNP who did not benefit from tourism increased hunting activities within the park.

ICDP Description

The Government agency managing SNP, in collaboration with the large international donor that has hired you as a consultant, has designed an ICDP at the site. The primary goals of the project are:

a) To provide grassroots-level sustainable economic alternatives for people in SNP's buffer zone, the RDFR. The assumption is that deforestation could be slowed by providing rural communities with economic alternatives.

b) To provide basic amenities to communities, such as schools and hospitals, in order to reduce poverty among communities in the RDFR.

The key aspects of the ICDP are:

- Establishment of community forests as part of technical assistance in forestry to help farmers without title undertake natural forest management, such as sustainable logging in the buffer zone
- Cash incentives to maintain forest cover and as a substitute for the sale of trees to loggers while families develop a reliance on other sources of income
- Loans to allow local groups to undertake activities that promote forest conservation, such as ecotourism and development of non-timber forest products
- In terms of agriculture alone, over a ten-year period, the project plans to grow from focusing on improved production for subsistence, to production for regional sales, to production for national markets, and finally to production for international markets

SITE 2

Description

The Rio Nuevo Conservation and Management Area (RNCMA) in Somoza is a large 92,614 ha biologically rich area legally owned and managed by a Non-Governmental Organization (NGO). The area contains an exceptional variety of vegetation types including hardwood forest, savanna, and wetlands, as well as diverse aquatic habitats. The forests of the RNCMA are recognized as having the richest stock of mahogany (a highly valuable timber species) in Somoza. Approximately 60% of the area is considered a core area where extraction is illegal. The remaining 40% of the area is designated as a buffer zone that the NGO considers suitable for sustainable resource use within RNCMA's boundaries. The NGO has a clear mandate to manage the area.

The RNCMA currently faces only minor human pressure on its resources. Forest cover is still extensive in the region, and human population density is low. Several international organizations have contributed an impressive level of support to the NGO managing the RNCMA. This support includes comprehensive biological field inventories, surveys, and monitoring. Having secured the protection of RNCMA (at least in the short term), the NGO is now challenged to plan for future population growth and land shortages by developing land-use practices that reconcile economic development and biodiversity conservation. The RNCMA is not an island of protected forest in a degraded landscape, but rather forms part of the largest remaining tract of Central American forest. The NGO managing the park has collected extensive and thorough information on resource use within the park and have a thorough understanding of the economic context. The institutional context is simple with the NGO as the primary manager of the conservation area.

Biodiversity protection in Somoza suffers from an absence of a unifying national conservation policy. Management priorities and regulations are variable between protected sites and the institutional framework for biodiversity conservation is diffuse. However, the Government has a pro-NGO policy in numerous governance activities such as identifying policy priorities, analyzing policy, and carrying out legal reform. The NGO enjoys strong political support from the central government and has successfully raised international funds for park management and administration.

Social and Political Context/Land and Resource Tenure Issues

Tenure changes are no threat within the park. Adjacent lands are generally stable. There are three primary land-uses surrounding the park: Private, government, and community-owned lands. Large, privately owned lands and Government-owned forest reserves are still forested and act as buffers to the core area of the RNCMA. To the north of the Park, Mestizo communities practice subsistence agriculture and produce sugar cane; however, many youths have begun to seek employment in urban centers and farming is becoming less popular. There is clear information on land and resource tenure within the park and good overall studies in surrounding areas. All lands within the Park are owned by the NGO. The fact that the NGO has exclusive property rights over its land simplifies conflict management regarding land tenure or resource use within the RNCMA. Within its boundaries, the NGO has so far been able to expropriate squatters, remove poachers, stop industrial exploitation, etc.

Threats

Currently, the area faces no single large-scale external threat. There are low levels of shifting cultivation and hunting in parts of the buffer zone adjoining community lands. No intensive resource extraction or agricultural activities are occurring in RNCMA or its buffer zone. In the future, population growth, agricultural intensification, and increased timber extraction threaten this ecosystem. A likely threat will be the increasing demand for its valuable hardwoods, although the NGO is attempting to thwart this through its sustainable logging program. Maintaining biologically sustainable timber harvest rates is likely to become more difficult in the future as timber resources are exhausted elsewhere and the wood becomes even more valuable. Population growth or uncontrolled immigration could also cause land-shortages in the future. Recognizing the threats, the NGO hopes to identify and promote economic activities that are compatible with biodiversity protection.

The NGO works to control illegal logging of valuable timbers by (1) restricting resource access by patrolling the area and confiscating any illegally harvested materials, and

(2) substituting illegal resource use with planned, low-impact resource uses. The NGO ensures that commercial hunting in the area is prohibited through strict patrolling.

Community Participation and Attitudes Towards RNCMA

There are no resident communities within the core area of the park although communities resident in the buffer zone occasionally hunt in the core area. NGO relations with surrounding communities are by and large neutral or positive. Clear and effectively enforced land-tenure rules have ensured stability in land-use by surrounding communities. Communities have been actively engaged in the design of ICDP activities relevant to them right from the very beginning. While most communities do not depend on the park resources for their subsistence or livelihood, there are at least 2 villages with a total population of about 150 people (30 families) who are extremely poor. Fifty per cent of the families depend on hunting and shifting cultivation in the buffer areas to meet their daily needs and the remaining are employed as laborers in coffee plantations outside the park boundaries. However, population growth within communities resident in the buffer zone is quite high.

ICDP Description

Given the potential for population growth, land shortages and increased demand for timber in the future, the NGO seeks to achieve sustainable development as one of its primary long-term goals. In this context, the NGO hopes to conserve the area through developing models of sustainable resource use in the buffer areas surrounding the park. The NGO has been funded by the donor organization which has hired you as a consultant to design an Integrated Conservation and Development Project (ICDP). The primary goals of the ICDP are:

a) To conserve the core area of the park and protect it from degradation.
b) To provide employment for growing populations in the buffer areas surrounding the park and help eliminate poverty in two villages.
c) To help fund management costs of the area.

The ICDP involves buffer zone and outreach activities in 2 categories:

- Extractive activities promoted within the park boundaries aimed at testing models of sustainable resource use, generating employment opportunities, eliminating poverty, and producing sufficient cash returns for the NGO to pay for perpetual care of the area
- Outreach activities beyond park boundaries designed to educate the public regarding the importance of conservation and to build positive relations between the Park

and neighboring communities

Non-timber forest products

The NGO has identified several non-timber forest products (NTFPs) from the area of potential commercial value, including chiclé, essential oils, honey, etc. Ideally, the sustainable harvest of these products is expected to eliminate poverty by helping meet the income needs of poor communities in the buffer zone. Chiclé extraction was a major industry in the country during the late 1800s through the mid 1900s, after which time production levels fell due to overexploitation, problems in production quality, and market collapse. The NGO is attempting to resuscitate chiclé extraction in the Park since there is an abundant population of sapodilla trees and has entered into a trial business arrangement. However, there is incomplete and outdated information on the abundance and distribution of sapodilla trees. The NGO plans to implement pilot projects in small plots of land within the Park.

Forestry

Timber harvesting is an integral part of the history of RNCMA. The NGO is currently developing a major program (as part of the ICDP) designed to sustainably harvest timber. A complete mapped inventory exists of the valuable hardwoods in the park. The NGO hopes that the program will contribute to local industry and employment, achieve economic viability, minimize impacts on biodiversity, and help support other management activities on site. Recognizing that establishing ecologically and economically sustainable resource use is an imposing challenge, the NGO is committed to a cautious and experimental approach.

The NGO:

- recruits technical input from expert biologists and foresters
- delineates preservation zones on fragile habitat
- budgets considerable investment into future research and monitoring
- aims at low-level extraction rates

In addition to the above activities, the ICDP aims to implement long-term biological monitoring of the core area as well as increase patrolling and enforcement in border areas that are vulnerable to encroachment.

You are invited as an external consultant to review, analyze, and predict the potential success or failure of the ICDPs at each of the sites.

ASSIGNMENT

1. What are the factors concerning **site characteristics** (for example threats) that you would consider as affecting the suitability of ICDPs? For each of these characteristics,

compare and contrast the two sites.

2. You are aware of critical **design criteria** for ICDPs that determine their potential success or failure. Analyze the ICDP descriptions that have been provided to you for each of the sites and predict the relative success or failure of the two projects on the basis of specific design criteria.

3. At Site 2, a key aspect of the ICDP involves two activities that are based on the **sustainable use** of resources within the park: (1) the development of sustainable extraction of non-timber forest products such as chiclé to help eliminate poverty in two villages in the buffer area of the park, and (2) the implementation of pilot projects in sustainable forestry primarily to generate income to support park management costs.

What are the critical factors that the NGO needs to carefully consider in developing its strategy of sustainable use of non-timber forest products as the means to help eliminate poverty in the two villages?

TERMS OF USE

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