Introduction to Marine Conservation Biology

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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