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Excerpt
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Part I

Key concepts

1 · *Introduction*

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1.1 Marine ecosystems

The Earth is a blue planet. Seas and oceans cover over 70% of the Earth's surface and, with an average depth of over 3.2 km, the total volume of marine ecosystems is vastly greater than that of terrestrial and freshwater environments combined, comprising 98% of the total inhabitable space on the planet (Speight and Henderson, 2010). Marine ecosystems contain 31 of the 33 phyla of animals, each of which constitutes a unique and distinctive body plan, with 15 of those phyla occurring only in the sea (Angel, 1993). Approximately 250 000 marine species have been described, with an estimated 750 000 still to be discovered (Census of Marine Life, 2010). Marine creatures include the largest ever to live (blue whales), yet the energy to fuel these giants is mainly captured by microscopic plankton, rather than more substantial plants, one of a number of fundamental differences between marine and terrestrial ecosystems (Steele, 1985, 1991; Webb, 2012). Of the global annual net primary productivity, approximately 104.9 petagrams (10^{15} grams) of carbon per year, around half is produced by marine ecosystems (Field *et al.*, 1998). Although coral reefs and beds of seaweed are, per unit area, among the most diverse and productive ecosystems on Earth, open oceans have levels of productivity akin to terrestrial deserts because life is so thinly spread, but nevertheless make the single greatest contribution to global productivity because of their size (Whittaker and Likens, 1975).

Archaeological records show that even the earliest humans exploited the marine environment for food, as a medium for transportation and as a repository for waste (Jackson, 2001; Jackson *et al.*, 2001). Today, the marine environment provides approximately 80 million tonnes per

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year of fish and shellfish from capture fisheries, representing about 3% of our global animal protein supply. Marine aquaculture contributes an additional 20 million tonnes (FAO, 2012). Therefore, marine ecosystems can be seen as having an important role in global food security (Frid and Paramor, 2012). It is increasingly recognised that they contribute much more than that to human well-being, in economic, social and cultural terms. This recognition was initially crystallised when Costanza *et al.* (1997) estimated that coastal seas, open oceans, estuaries and saline marshes provide an estimated 68% of the total economic value of all ecosystem goods and services derived from the natural environment. Whilst the detail of Costanza *et al.*'s valuations has been subsequently disputed by environmental economists, their analysis did alert a much wider audience to the overwhelming importance of marine environments to human well-being. More recently, Sumaila and Cisneros-Montemayor (2010) estimated that globally 121 million people a year participate in ecosystem-based marine recreational activities, generating 47 billion USD (2003) in expenditure and supporting one million jobs.

For many years, marine ecosystems were considered to be inexhaustible sources of bounty and a convenient and resilient dumping ground. In fact, even early human societies were capable of exploitation at levels that were, in modern parlance, unsustainable. For example, Stone Age rubbish tips around the Mediterranean show that the size of the shellfish being exploited decreased over time and then the resource collapsed (Desse and Desse-Berset, 1993). It is now recognised that human activities are degrading marine ecosystems in many places through overfishing and activities that cause habitat destruction, pollution and the spread of invasive species (Millennium Ecosystem Assessment, 2005; Halpern *et al.*, 2008). Much of that degradation is out of sight and largely out of mind for much of society. Nevertheless, there is a groundswell of support for conservation and more sustainable exploitation, driven in part by high profile issues and events, such as overfishing, algal and jellyfish blooms and major oil spills, as well as improving public awareness of the beauty and fragility of the marine realm.

Given their great richness and long-standing cultural importance, a strong argument can be made that marine ecosystems deserve conservation on purely aesthetic and moral grounds. However, new arguments are being made alongside these that require a new way of thinking and a particular kind of scientific underpinning.

1.2 Ecosystem services, ecosystem functioning and biodiversity

Ecosystem services are an emerging driver of conservation policy and a component of the ecosystem approach to environmental management (Millennium Ecosystem Assessment, 2005; UNEP, 2010; UK National Ecosystem Assessment, 2011). They can be defined in terms of the contributions of ecosystems to human well-being, encompassing both tangible goods such as food and raw materials, but also more intangible services such as climate regulation, flood protection and cultural and aesthetic enrichment (de Groot *et al*., 2010; TEEB, 2010). There is a clear distinction between ecosystem services, which are made available by ecosystems and the benefits that society chooses to derive from them. Thus, ecosystem services should be considered from an ecological perspective and benefits must be considered and measured from social, economic and health perspectives. It is the benefits which can be measured in value terms such as monetary units, as well as through other non-monetary value systems such as happiness, employment, and health improvement (Chapter 2), and thereby be more easily taken into account in environmental policy and management decisions, that can be justified in terms understood by the public and politicians. The prominence of ecosystem services in the international policy arena is underscored by the recent establishment of the Intergovernmental Panel on Biodiversity and Ecosystem Services to promote and inform the application of the concept in policy and management.

Delivery of ecosystem services depends on the efficient functioning of ecosystems (Worm *et al*., 2006). Ecosystem functioning can be defined in a number of ways (Paterson *et al*., 2012), but can broadly be described as the processing of energy and materials by ecosystems. Ecosystem functioning is quantified by measuring the rates of ecosystem processes. Ecosystem processes include primary and secondary production, respiration, decomposition, nutrient cycling and flows of energy through food webs (trophic dynamics). These major processes encompass functional pathways such as photosynthetic activity, nutrient fluxes and uptake, sediment mixing and stabilisation and clearance of particles from the water column. Community ecological processes, such as predation, herbivory, parasitism, mutualism and competition also influence ecosystem processes, particularly trophic dynamics, and are included in some definitions of functioning (e.g. Lawton and Brown, 1993; Martinez, 1996; Duffy 2009).

It is worth making clear distinctions between the structure of ecosystems, their properties and their functioning. The structure of an ecosystem constitutes its physical and chemical properties and the identity and relative abundance of its biological constituents (or biodiversity – see below). An ecosystem property can be defined as any aggregate structural variable describing the state of the system, such as biomass or sediment nitrogen content, and an ecosystem function as any aggregate process, such as production or grazing rate (Duffy, 2009). The stability of the structure and functioning of an ecosystem can be thought of as one of its key properties, and again comprises a number of distinct facets (see Chapter 3). Resistance to invasion is also an ecosystem property, essentially a particular aspect of stability, that has received considerable attention in this context (Stachowicz *et al.*, 2007). Pacala and Kinzig (2002) also discuss these distinctions but consider stocks, fluxes and stability as different aspects of ecosystem functioning. These terms correlate more closely with the interdisciplinary (natural and social sciences) terminology used to quantify ecosystem services and the benefits that arise from them.

The functioning of ecosystems and the services they provide depend on biodiversity and environmental conditions (Balvanera *et al.*, 2006; Stachowicz *et al.*, 2007; Naeem *et al.*, 2009). Biodiversity is another term that is used by many people to mean many things. Since being coined in 1988 (Wilson and Peters, 1988), it has found its way into the public lexicon becoming a byword for wildlife and used as a rallying call for conservation. In the broadest terms, it can be thought of as the variety of life, encompassing genes, organisms and habitats or ecosystems (United Nations, 1992) and is a key aspect of ecosystem structure. A given area that contains populations with high levels of genetic variability, many different species, many different habitat types or all three can be thought of as having high biodiversity. Although for most people, the number of species is the most obvious aspect of biodiversity, it is also worth taking account of which species are present, their relative abundances, the functional roles they play and the ways in which they are related to each other. In recent years, there has been extensive research establishing a link between the functioning of ecosystems and the biodiversity they contain. It is now widely accepted that, on average, loss of biodiversity causes reductions in the rates of many ecosystem processes, although this generalisation masks a much more complex story (see Chapter 5). There are complex feedbacks between the biodiversity in an ecosystem and the physical and chemical conditions and many of these remain unresolved.

As emphasised by a number of authors (e.g. Srivastava and Vellend, 2005; Duffy, 2009), it is important to make a clear distinction between changes in ecosystems and their consequences for society. Changes in ecosystem structure and functioning, whether positive or negative, large or small, are not necessarily either 'good' or 'bad' for society. In contrast, an ecosystem service is considered to have some positive value to human well-being, but it is not necessarily clear whether, on balance, a particular change to an ecosystem process should be considered beneficial or harmful. For example, an increase in primary production induced by nutrient inputs can be considered either positive for society (e.g. by increasing the productivity of a fishery) or negative (e.g. by degrading water quality via eutrophication). Traditionally, ecosystem scientists have primarily been concerned with characterising patterns and processes of ecosystem change in purely objective terms. As emphasised in this book, they are increasingly engaging with social scientists and economists to explore the equally complex challenge of assessing their consequences for society (e.g. Barbier *et al.*, 2011; Isbell *et al.*, 2011), which requires considerations of trade-offs that are not purely related to the consequences of ecosystem change but have wider social, economic and often political dimensions. Given that human activities are both causing biodiversity loss and changing environmental conditions (Millennium Ecosystem Assessment, 2005), it is essential that these consequences are better understood to better inform societal responses and actions.

1.3 Policy and legislative context

In September 2000, world leaders came together at the headquarters of the United Nations and adopted the UN Millennium Declaration (United Nations, 2000). This set a series of time-limited targets, that became known as the Millennium Development Goals (MDGs) (Table 1.1a), to be achieved by 2015. Progress in meeting these goals has been a central tenet of UN development work and international policy ever since. While human health and security dominate these goals, two are tightly linked to ecological processes. MDG1 can be summarised as food security and MDG7 as sustainability and the targets for these goals (Table 1.1b) provide the international policy context for the development of much of the environmental agenda in the first part of the twenty-first century.

Perhaps the single most important international agreement driving the conservation of biodiversity pre-dates the establishment of these goals,

Table 1.1 *(a) UN Millennium Development Goals and (b) the targets associated with Goals 1 and 7, which have the most direct links to ecological processes.*

		(a)	
Goal 1		Eradicate extreme poverty and hunger	
Goal 2		Achieve universal primary education	
Goal 3		Promote gender equality and empower women	
Goal 4		Reduce child mortality	
Goal 5		Improve maternal health	
Goal 6		Combat HIV/AIDS, malaria and other diseases	
Goal 7		Ensure environmental stability	
Goal 8		Develop a global partnership for development	
		(b)	
Goal 1	Eradicate extreme poverty and hunger	Target 1	Halve, between 1990 and 2015, the proportion of people whose income is less than $1 per day
		Target 2	Halve, between 1990 and 2015, the proportion of people who suffer from hunger
Goal 7	Ensure environmental stability	Target 9	Integrate the principles of sustainable development into country policies and programmes and reverse the loss of environmental resources
		Target 10	Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation
		Target 11	Have achieved by 2020 a significant improvement in the lives of at least 100 million slum dwellers

however. The Convention on Biological Diversity (CBD) was agreed in Rio de Janeiro in 1992 and has been ratified by the majority of the world's nations (United Nations, 1992; Convention on Biological Diversity, 2013). In the run up to the 20th anniversary of the CBD, the international community met in Nagoya, Japan, and agreed five Strategic Goals for global biodiversity and backed these with 20 quantified and time-limited targets (UNEP, 2010; Table 1.2). In both agreements, the fundamental dependence of human life (and lifestyles) on functioning ecosystems through ecosystem services and benefits provides the underlying rationale for conserving biodiversity and natural ecosystems. This has been a key factor in the propagation of that rationale in conservation

Table 1.2 *Strategic goals of the Convention on Biological Diversity's strategy for 2011–20 (UNEP, 2010). Each Strategic Goal has a set of associated Aichi Targets (20 in total) which provide a more detailed set of aspirations, such as: at least halve and, where feasible, bring close to zero the rate of loss of natural habitats; establish a conservation target of 17% of terrestrial and inland water areas and 10% of marine and coastal areas; restore at least 15% of degraded areas through conservation and restoration activities; make special efforts to reduce the pressures faced by coral reefs.*

Strategic Goal A	Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society
Strategic Goal B	Reduce the direct pressures on biodiversity and promote sustainable use
Strategic Goal C	To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity
Strategic Goal D	Enhance the benefits to all from biodiversity and ecosystem services
Strategic Goal E	Enhance implementation through participatory planning, knowledge management and capacity building

policy and practice to many parts of the world, driving the establishment of a range of legislative instruments at regional and national scales.

At a national level, most governments have a developed system of planning and environmental management and regulation for activities occurring within their terrestrial territories. The extent to which these extend across the intertidal and into the coastal seas is highly variable. Many countries have or are developing approaches, broadly grouped as 'coastal zone management', that seek to provide integrated planning and environmental protection for the coastal zone. These generally focus on development, infrastructure and sea defences with water quality and fisheries managed by separate processes. The development of the UN Convention on the Law of the Sea (UNCLOS) provided a framework for the development of legislative frameworks covering the high seas (beyond 12 nautical miles from the coast).

UNCLOS allows nations with a coastline to establish Exclusive Economic Zones (EEZ) out to 200 nautical miles from their coasts (or to the median line with another state). Within its EEZ, each nation controls the exploitation of living and non-living resources. The UNCLOS was first published in the 1970s (having been in negotiation since the early 1950s) but the value of the potentially rich mineral resources on and under the seafloor have ensured that claims and counter claims for parts of the ocean floor continue to be made to this day. Even if agreement was reached on the geographically defined units that constitute each nation's EEZ, biological resources and ecological processes extend across these boundaries.

A variety of international treaties have been agreed to address the transboundary nature of, for example, pollution dispersion and fish stock migration (e.g. United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks; United Nations, 1995). The CBD ushered in a more holistic approach to environmental management, requiring protection of functioning ecosystems (United Nations, 1992). This has created an impetus to develop environmental management of the seas and oceans around ecological boundaries. A decade-long study initiated by the UN Environment Programme (UNEP) and driven by the US National Oceans and Atmosphere Authority (NOAA), has delimited and characterised the world's Large Marine Ecosystems (NOAA, 2009; Sherman and Hempel, 2009). These large units are being used, to some extent, as management units when they fall entirely within the jurisdiction of a single authority (EU, Australia, Canada) but, to date, there has been little international collaboration to develop management around such ecologically based areas.

In 1997, Canada became the first nation to introduce a legislative framework for integrated management for its EEZ. The Canadian Oceans Act has three guiding principles; sustainable development, integrated management and a precautionary approach. Five spatial management units, known as Large Ocean Management Areas (LOMAs) were designated and a commitment made to develop management plans for each one. The smaller of the LOMAs (i.e. the Beaufort Sea and St Lawrence Seaway) might be regarded as ecological units. In 2002, a strategy document was published and this in turn led to an action plan for management within the LOMAs that was published in 2005. Since then the focus has been on establishing the current health of the ecosystems and identifying the main threats to maintaining healthy seas.

Other holistic marine ecosystem management initiatives include the EU Marine Strategy Framework Directive and the US and Australian 'aspirational' ocean policy documents. For example, the US government has produced a framework document published in 2004 entitled *An Ocean Blueprint for the 21st Century* (US Commission on Ocean Policy, 2004). It is not a statutory instrument but seeks to facilitate federal, regional and local initiatives and foster the development of a common