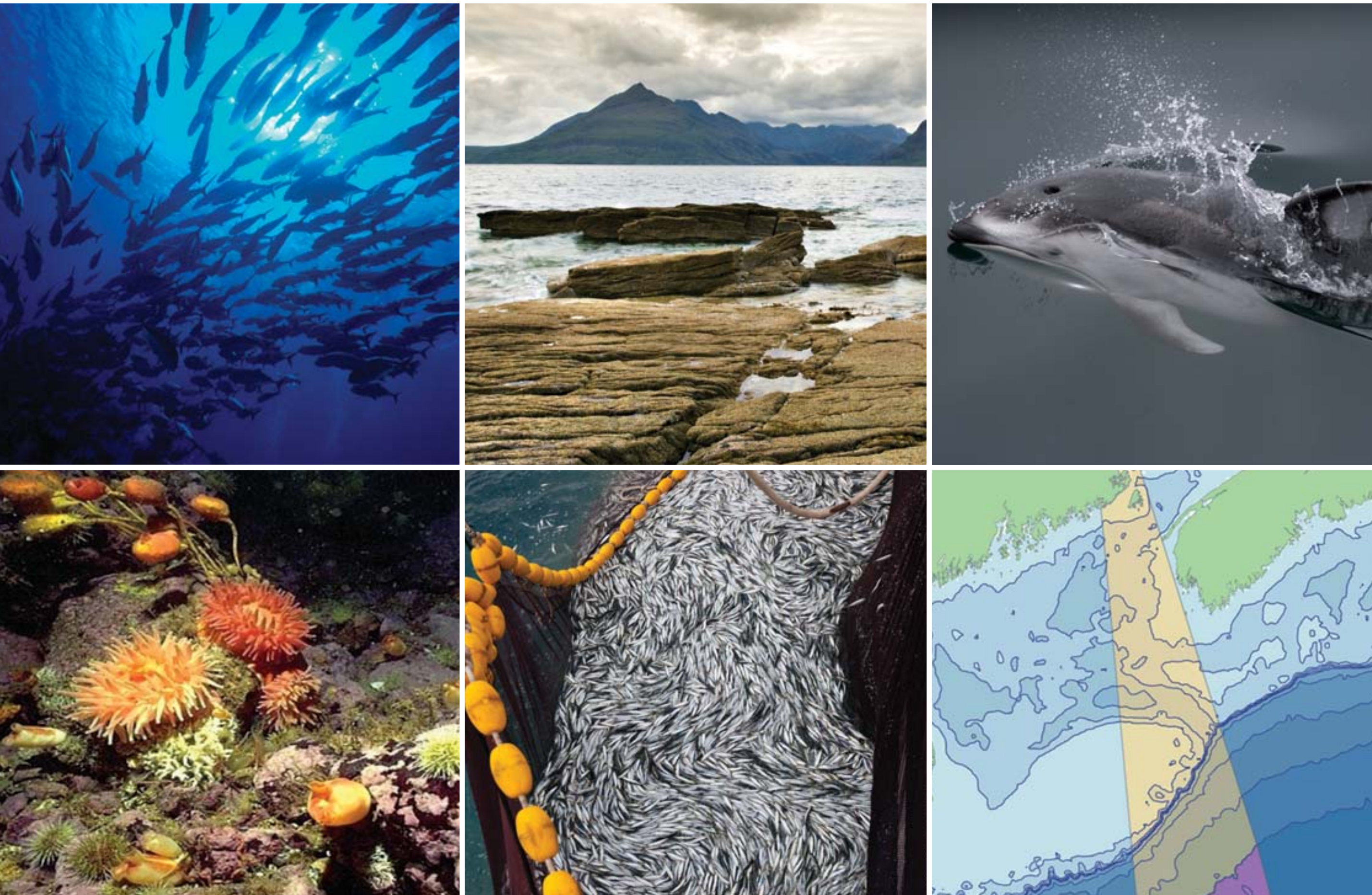
John Roff and Mark Zacharias

Marine Conservation Ecology



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John Roff and Mark Zacharias
with early contributions from Jon Day

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For Elizabeth and Karen

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Preface

Marine Conservation Ecology: Concepts and Frameworks

The oceans have traditionally been conceived of as boundless and beyond the realm of significant human impacts; the great fisheries of the world were once considered as essentially limitless. By 1883, even though economic pressures on fisheries were already being felt, T. H. Huxley boldly announced that 'Any tendency to over-fishing will meet with its natural check'. We now know that these conceptions are false. Worldwide, fisheries are in decline – perhaps irreversibly in some cases – and marine habitats have become extensively degraded. Marine conservation is no longer an option – it is a pressing necessity. However, despite many well intentioned – but generally disjointed – efforts, marine conservation is not yet firmly based on ecological foundations. Nevertheless, we can recognize general principles, concepts and even paradigms, and use these as an experimental basis for planning frameworks and decision making. This in turn requires ecological classifications. The history of science (whatever the discipline) shows how '…the development of comprehensive theoretical systems seems to be possible only after a preliminary classification has been achieved' (Nagel, 1961). This is what this book is all about, but there is little here that is canonical. It has often been said that biology has only one theory – evolution by natural selection. If this is so, then conservation has no real theories at all, it is a pragmatic science. We, the authors, simply hope to present a practical set of approaches to marine conservation that can be used as the basis of frameworks for planning.

We cannot protect the whole of the marine environment – some parts of it will always be open to exploitation and disturbance due to resource use by humans. Therefore, just as in terrestrial conservation, choices need to be made as to what will be protected. But how, on what basis, according to what criteria, do we select those pieces of the ocean that we should protect so as to maximally preserve (or at least efficiently protect) the greatest proportion of the components of marine biodiversity? This is the prime thrust and interest of this book.

We argue that places to be protected (which we shall generally refer to generically as MPAs – marine protected areas) need to be selected systematically on the basis of our knowledge of the ecology of the seas. By 'ecology' we mean simply 'the science of relationships between organisms and their environments'. Such ecological information is inevitably incomplete. This book therefore deals with the principles and criteria underlying the selection of MPAs, rather than the specifics of where conservation is required. However, we shall include specific examples of the process of selection of protected areas. In this book we cannot hope to address all the problems of marine conservation. However, through an examination of ecological principles, and a study of the nature of the marine environment, we can present the issues that need to be addressed in a systematic way. What we are attempting then is a 'codification' of the undertaking of marine conservation. By this we mean that we shall examine the various problems that arise in attempting to deal systematically with the practicalities of marine conservation, to show what they are and how they can be dealt with from available or obtainable data. The main aim of this book therefore is to present the major ecological concepts of and approaches to marine conservation, with an emphasis on protected areas – MPAs.

Books currently available on ‘marine conservation’ tend to fall into several categories. There are those that emphasize the conservation of individual species, especially rare and endangered species, typically marine mammals; those whose emphasis is on resource conservation, typically commercially exploited species – especially fisheries; others that issue ‘wake-up calls’ or ‘calls-to-action’ concerning marine biodiversity and the need for marine conservation; and those that deal with the identity and operation of MPAs based on socio-economic principles. We applaud all these efforts and approaches to marine conservation, and the need for another text on marine conservation may not be readily apparent. However, none of the available texts on marine conservation primarily emphasizes the overall ecological foundations of the discipline. Several of them are not scientifically rigorous, and contain little in the way of hard scientific information. In general they do not consider or integrate science-based approaches to marine conservation, or the ecological logic for planning and establishment of MPAs.

The purpose of this book then is to present the science of marine biodiversity and marine conservation. Specifically, we deal with marine biodiversity and the importance of establishing MPAs to offset threats to it. This in turn requires an understanding of the structure and function of marine environments and the ecological foundations of approaches to and options for marine conservation. We show how conservation initiatives, primarily those based on the establishment of MPAs, can be firmly based on accepted ecological principles, and can be integrated into comprehensive regional and international frameworks. Such a systematic approach, starting with the codification of the components of marine biodiversity, can ensure that we both rationalize the roles of existing MPAs and identify needs for further ones. Only such coordinated regional, national and international planning can ensure that global marine biodiversity is adequately evaluated, represented and protected.

This book explores the theory and practice of marine conservation, and importantly the process of establishment of MPAs, from the perspective of ecological principles. There is, in our opinion, a clear need for a foundational text that emphasizes marine conservation from an ecological approach. Planning for conservation also necessarily involves: social, political, economic, legal and ecological issues. However, of all these subjects, ecological issues have perhaps been most weakly addressed in terms of marine conservation. It is this important gap in marine conservation knowledge and practice that we seek to fill. In an era of change from uni-disciplinary through multi-disciplinary to inter- and trans-disciplinary studies, and with an enterprise as complex as marine conservation, it may seem anachronistic to base a text solely on the discipline of ecology. In developing conservation plans, it has frequently been argued that we cannot view ecological systems in isolation: human socio-economic activities must also be accounted for. We completely agree. However, all conservation plans must be firmly grounded in ecological principles if they are to systematically address the requirement for conservation of the components of biodiversity. Conservation without the reality of the human dimension is incomplete; conservation without the ecological dimension is unreal! We should perhaps recall the etymology of the word ‘ecology’ (Gk. Oikos – Home). If we cannot understand our own home then we cannot be of much assistance elsewhere beyond it whether in space, time or discipline.

Because our focus in this book is on the ecological basis and principles for marine conservation, we shall be less concerned with other aspects of marine conservation such as: international conventions, marine management, policy, legislation, enforcement, socio-economics and the human dimensions in general. These subjects will inevitably impinge upon our material, but other recent texts deal with them in much greater depth. Thus this book is not so much about human regulatory efforts or human impacts on the oceans (though they will enter into it), but rather it is about the steps we can take to protect the components of marine biodiversity by systematically reserving areas, and how such actions can be founded in ecological principles. We well recognize the significance of other disciplines and the need to integrate them in the process of planning for marine conservation as a whole, but our overarching theme is the ecology of marine biodiversity and its conservation. Nor have we emphasized subjects well covered elsewhere in standard texts – such as population biology and ecology, and fisheries biology. A primary interest is on MPAs – not because the establishment of MPAs is the only thing we should do, but because it has been repeatedly shown that MPAs are effective in protecting 'pieces' of the marine environment and their species. MPAs can be thought of as a necessary but not a sufficient contribution to integrated marine conservation.

Our emphases are primarily on: the identity and components of marine biodiversity, potential approaches to the conservation of marine biodiversity, its relationships to environmental structure and heterogeneity, and the planning of practical marine conservation strategies at the regional and national levels. The main rationale for this approach is that: although concerns for the preservation of marine biodiversity are truly global and international, nevertheless most planning and practical initiatives to conserve marine biodiversity will be undertaken at the national and regional levels. The intention is not to ignore or gloss over other aspects of – or disciplines in – marine conservation; rather it is to emphasize the fundamental importance of ecological knowledge and planning.

An ecological approach to marine conservation requires fundamental knowledge of: the environment, the organisms that inhabit those environments and their habitats, and the biological and physical interrelationships between them. In short, we need to know about the structure and function (processes) of the marine environment in physical and biological terms. It is these environmental and ecological foundations, and the principles that we can derive from them, that are vital in developing our strategies for marine conservation, yet unfortunately this is precisely what is missing from much of the marine conservation text book literature. Even in the primary research literature, such subjects are scattered and unsystematically treated.

A single text that would systematically and comprehensively cover marine environments, the range and diversity of their habitats and communities, biological and physical interrelationships structure and function, and conservation strategies and protected areas planning would be an overwhelming treatise. We do not propose such a treatise. The reader must perforce be referred to other sources for more comprehensive and systematic treatments of each of the major component disciplines and their techniques on which marine conservation planning must call. However, this text is an attempt to organize systematically an approach and overall frameworks, and – at least at a foundational level – to present the various disciplines and indicate their place and role in marine conservation.

There will inevitably be some repetition in this book because there are so many interactions among the subjects to be considered. But the flow of ideas and subjects in the book is as follows.

First, we treat the fundamental issues of what marine biodiversity actually is, and why we should be concerned about it – because of its significance and the various threats to it. Next we describe the basic structure of the marine environment – its major divisions, physico-chemical properties, ecology and biological communities. We continue by examining measures to address the threats to marine biodiversity, by means of various approaches to marine conservation – including strategies for designating MPAs. Here we consider the benefits of marine conservation and the need for a systematic approach and scientific knowledge of the oceans in the decision-making process. We argue for and rationalize the need for a systematic set of approaches, based on hierarchical 'structural' and 'functional' attributes at the genetic, population, community and ecosystem levels of organization. Because most conservation initiatives have been in terrestrial environments, and are based on terrestrial ecological principles, we examine how and why marine systems are different from terrestrial ones, and why they must be treated differently.

We then separately consider the approaches that could be taken towards marine conservation at each 'level' of ecological hierarchies from global to local, and from 'ecosystems' to genes. We consider global biogeographic classification schemes, and what is meant by ecosystem-level approaches to marine conservation. Regional 'representation' at the habitat or ecosystem level and the significance of geophysical attributes of marine environments as surrogates for marine community types is then dealt with, including an examination of relationships between habitats and community properties. Next, crossing the boundaries of the ecological hierarchy, we examine relationships between individual species and ecosystem processes in distinctive areas, including seasonally migrant species that exploit them, and show how they can be recognized and defined. Continuing at the species level, the distribution of species diversity in global and regional 'hotspots' is considered, along with underlying causative factors. Still at the species level, we examine 'focal species' and why some species may deserve more attention than others. Finally, we come to the genetic level and show its growing significance to understanding processes at all the other levels of the ecological hierarchy. The marine coastal zone and deep seas and high seas are each treated separately for a variety of reasons that are explained and rationalized. Fisheries management and its implications and impacts on marine biodiversity as a whole are then considered, and the emerging and vital process of integrating conservation of fisheries and biodiversity is explored.

The next task is to integrate the different approaches to marine conservation based on all the separate levels of the ecological hierarchy, in order to define potential 'sets' of candidate protected areas. Such 'sets' of MPAs should – collectively and ideally – afford protection to 'all' the elements of marine biodiversity. Here we show how the number, size and boundaries of MPAs can be defined, and argue how the proportion of a region to be protected can be established. Following this we examine the concept and meaning of 'value' itself, and suggest how to assess and evaluate conservation efforts. We consider the criteria for selecting 'sets' of candidate MPAs, and for the establishment of 'networks' of MPAs, based on patterns of connectivity from analysis of oceanographic and genetic data. The important but often neglected process of monitoring of conservation efforts is next considered. Finally, we indicate some of the many remaining problems for marine conservation.

Inventories of the global set of MPAs have now been assembled; however, we still have an incomplete idea of what level of protection these areas actually afford to their marine inhabitants or visitors. Most importantly, we still have little idea of what, either individually or collectively, these areas contribute to the protection of the world's components of marine biodiversity. This is surely the next step – to codify the contributions of the world's 'set' of MPAs in terms of their roles in biodiversity protection, and their roles as members of regional, national and international members of networks of MPAs. Following this, a global gap analysis programme (GAP) will indicate what we are missing and where. However, without an overall framework such as presented in this book, it is far from clear how this task would be accomplished.

Optimistically, human populations will eventually stabilize, and our environmental impacts on the globe will become sustainable. Whether this will happen or not is not really in question. The question is simply whether the transition to population stability and environmental sustainability is achieved gently or catastrophically. This book is concerned with the interim – between now and a sustainable future. It is concerned with no less than the fundamental ecological and environmental principles of how to go about planning to conserve the full array of marine biodiversity assets of our planet. How do we plan for a network of new-age Noah's Arks (or perhaps better – Noah's submarines!) to carry over our assets for the future? Ultimately MPAs should become redundant – once humans have learned to live in harmony with their environment and to treat it with respect.

The intended audience for our book consists primarily of senior undergraduate and graduate students of marine biodiversity and conservation, government and non-government agencies and their planners, managers and practitioners who are responsible for the implementation of national, regional or local strategies. However, we hope the text will also appeal to a broader audience with interests in marine ecology and marine conservation, and that it will help them to place their own discipline and actual or potential role into perspective.

Reference

Nagel, E. (1961) *The Structure of Science*, Hackett, Cambridge

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Acronyms and Abbreviations

AEC	adaptive evolutionary conservation
AFLP	amplified fragment length polymorphism
ACM	Atlantic continental margin
BVM	biological valuation map
CA	correspondence analysis
CBCRM	community-based coastal resource management
CBD	Convention on Biological Diversity
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CETAP	Cetacean and Turtle Assessment Programme
CoML	Census of Marine Life
CPUE	catch per unit effort
CRM	coastal resource management
CZM	coastal zone management
dB	decibel
DCA	detrended correspondence analysis
DCCA	de-trended canonical correspondence analysis
DEFRA	Department for Environment, Food and Rural Affairs
DEM	digital elevation model
DFO	Department of Fisheries and Oceans Canada
DPS	distinct population segment
EAF	ecosystem approach to fisheries
EAM	ecosystem approaches to management
EBM	ecosystem based management
EBSA	ecologically and biologically significant area
EcoQO	ecological quality objectives
EEZ	exclusive economic zone
ENSO	El Nino Southern Oscillation
ESA	US Endangered Species Act
ESU	evolutionary significant unit
FAO	Food and Agriculture Organization
GAP	gap analysis programme
GBRMP	Great Barrier Reef Marine Park
GHNMCA	Gwaii Haanas National Marine Conservation Area
GIS	geographic information system
GOOS	global ocean observing system
HSI	habitat suitability indices
ICM	integrated coastal management
ICZM	integrated coastal zone management
IDH	intermediate disturbance hypothesis
IFQ	individual fishing quota
IGOS	Integrated Global Observing Strategy
IOC	Intergovernmental Oceanographic Commission
IUCN	International Union for the Conservation of Nature
IVQ	individual vessel quota
JNCC	Joint Nature Conservation Committee
LME	large marine ecosystem
MARPOL	marine pollution (short form of International Convention for the Prevention of Pollution from Ships)
MEF	modified effective fetch
MEoW	marine ecoregions of the world
mi	mile
MIP	molecular imprinting
MNCR	Marine Nature Conservation Review

MPA	marine protected area
MRU	marine representative unit
MSPR	mortality and spawning potential ratio
MSY	maximum sustained yield
mtCOI	mitochondrial cytochrome oxidase I
mtDNA	mitochondrial DNA
MU	management unit
MVP	minimum viable population
NAO	North Atlantic Oscillation
NAEWC	North Atlantic Right Whale Consortium
Nc	census population size
Ne	effective population size
NER	non-extractive reserve
NMFS	National Marine Fisheries Service
NIS	non-indigenous species
nmi	nautical mile
NMS	non-metric multidimensional scaling
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
OBIS	ocean biogeographic information system
OCP	organochlorine pesticide
OOI	Ocean Observatories Initiative
OSPAR	Oslo and Paris Convention
OSY	optimum sustained yield
OTN	Ocean Tracking Network
PAH	polycyclic aromatic hydrocarbon
PCA/PAC	priority conservation area
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzodioxin
PCDF	polychlorinated dibenzofuran
PCM	Pacific continental margin
PcoA	principal components analysis
PCM	possibilistic C-means
PCR	polymerase chain reaction
ppm	parts per million
ppt	parts per thousand
PSAMP	Puget Sound Ambient Monitoring Programme
PSR	pressure-state-response
psu	practical salinity unit
PVA	population viability analysis
RAP	Representative Areas Programme
RAPD	random amplified polymorphic DNA
RMP	Revised Management Procedure
ROI	return on investment
RFLP	restriction fragment length polymorphism
SEK	scientific ecological knowledge
SFG	scope for growth
SMEH	seamount endemicity hypothesis
SPUE	sightings per unit of effort
SSB	spawning stock biomass
SSBR	spawning stock biomass per recruit
STR	short tandem repeat
TAC	total allowable catch
TEK	traditional ecological knowledge
TIE	toxicity identification and evaluation
UKMMAS	UK Marine Monitoring and Assessment Strategy
UNCBD	United Nations Convention on Biodiversity
UNCED	United Nations Conference on Environment and Development
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNICPOLOS	United Nations Informal Consultative Process on Oceans and the Law of the Sea
UNTBB	unified neutral theory of biodiversity and biogeography
NODC	US National Oceanographic Data Center
VRM	vector ruggedness measure
WMO	World Meteorological Organisation
WWF	World Wide Fund for Nature

1

Introduction: Why Marine Conservation is Necessary

Significance, threats and management of the oceans and biodiversity

> *We set sail on this new sea because there is knowledge to be gained.*
>
> John F. Kennedy (1917–1963)

Fundamental significance of the oceans

Homo sapiens has a very biased view of planet Earth; its proper name should be Oceanus or Water. The oceans are the dominant feature of our planet, covering nearly 71 per cent of its surface. Indeed, a view of the Pacific Ocean of our 'Earth' from space shows hardly any land at all (Colour Plate 1a). Although most of us now live in cities, removed from direct interaction with natural environments, as a terrestrial species humans are nevertheless familiar with the 'structures' of the land – the physiography of its mountains and valleys and landscapes. The plants and animals of the land comprise our food and natural environments, and we also daily encounter the terrestrial 'processes' such as radiation from the sun, rain and winds.

We have no such inherent perceptions for the oceans. Their structures and physiography – canyons, seamounts, depths and plains – are hidden from us. The character of seawater and ocean 'climate', and oceanic processes including the myriad types of water motions are not appreciated. The wind waves we see as we travel the surface of the oceans are largely irrelevant to its biota. Apart from an occasional meal of fish, the plants and animals of the oceans are alien to us – indeed we would need a microscope to see the most common among them. This perceived remoteness of the oceans was probably responsible for the predominant interest in terrestrial conservation at the expense of conservation of the oceans (see Irish and Norse, 1996).

The oceans contain a unique molecular substance – water – whose anomalous properties would not be predicted from comparisons to other related compounds (see e.g. Franks, 1972). Life on Earth (hereafter 'earth') originated in the oceans and is only possible because of the unique physico-chemical properties of water. Together, the thermal, colligative and dielectric properties of water circumscribe both the characteristics of life on earth and its physical limits and distribution. Life on earth can exist from the summits of mountains to the depths of the oceans. With a few minor exceptions (including mercury and oils) water is the only naturally occurring liquid on earth. It is THE essential ingredient of – and

Box 1.1 Most of the properties of the oceans depend on the properties of water itself

Property	Comparison to other liquids	Importance
Heat capacity	Highest except for NH_3	Planetary thermostasis and heat transfer
Latent heat of fusion	Highest except for NH_3	Thermostatic effects
Latent heat of evaporation	Highest of all liquids	Thermostasis and heat transfer
Thermal expansion	Temperature of maximum density	Controls circulation of the oceans
Surface tension	Highest of all liquids	Cell physiology and ecology
Dissolving power	Highest of all liquids	Major implications for physical and biological processes
Dielectric constant	Highest of all liquids	Enables high chemical dissociation
Transparency	Relatively high	For photosynthesis, predation
Heat conduction	Highest of all liquids	Outweighed by eddy processes

Source: Adapted from Sverdrup et al (1942)

for – all life as we know it. In the oceans it provides not only habitats for an enormous diversity of life forms, but also buoyancy for the largest organisms the world has ever-known – the great whales. Although they are air-breathing animals like humans, they cannot support their own mass on land.

The oceans are responsible for the regulatory control of conditions on earth, including climate in both the oceans and on land; the oceans modulate and moderate the terrestrial climate. It is no exaggeration to state that life in the oceans could continue perfectly well in the absence of any land on our planet at all. However, life on land without both the climate control and water reservoir of the oceans is unthinkable. In the South Pacific Ocean, the El Nino Southern Oscillation (ENSO) drives global climates, regionally modified by variations in other oceans such as the North Atlantic Oscillation (NAO). Sea temperatures partly determine the generation and intensity of destructive typhoons and hurricanes.

Marshall McLuhan (1962) in his seminal works first defined the concept of 'the global village'. With the subsequent rise of environmental movements and expansion of global trade and communications, the significance of the oceans to us – a terrestrial species – has finally dawned. Human civilization has now reached a point where its actions can cause changes at the planetary level. Global issues, including climate change, rising levels of CO_2 and global warming, now dominate our environmental concerns. But it is the homeostatic effects of the oceans – their

Box 1.2 Importance of the oceans

Globally, the oceans are the:

- main reservoir of water: 71 per cent of the earth's surface is covered by oceans; less than 0.5 per cent is freshwater;
- main place for organisms to live; they comprise over 99 per cent of the inhabitable volume of the 'earth';
- main planetary reservoir of O_2;
- possible main planetary producer of O_2 from phytoplankton;
- planetary thermal reservoir and regulator;
- medium for longitudinal heat transfer and circulation;
- major reservoir of CO_2 especially in HCO_3-, CO_3= forms;
- habitat for enormous diversity of living organisms, from bacteria to whales;
- reservoirs of enormous resource potential, both renewable and non-renewable, oil, minerals, etc.; also, about 50 per cent of global carbon fixation occurs in the sea.

productive and regulatory capacity – that have in large part mitigated our adverse environmental effects, and prevented things from being much worse than they presently are.

The primary producers of the oceans provide about one half of our atmospheric oxygen, and the deep oceans provide a major sink for the sequestration of atmospheric CO_2. Perhaps the most frightening scenario of potential environmental disaster is the possibility that deep ocean circulation may again cease (as it has in past geological periods), but this time with 'run-away' global warming. In more immediate human terms, the oceans are a major source of protein from fisheries, and the major trade routes among nations. Coastal zones provide an abundance of natural resources and nursery and recruitment areas for exploited species. The list goes on!

The present state of marine systems

The oceans are in a parlous state. For centuries, the oceans were thought be immutable and immune to human activities. Fish were plentiful and the capacity for the oceans to absorb human waste was believed to be unlimited. In 1605, Hugo Grotius – a Dutch jurist – laid the foundations for the International Law of the Sea by formulating the new principle '*Mare liberum*' that the sea was international territory and all nations were free to use it for trade. Apart from a narrow coastal fringe that could be protected by land-based cannon, the seas had become a 'commons' – open to all to use and abuse. Predictably, and historically, two things happened: the 'tragedy of the commons' (Hardin, 1968) and progressive protection of coastal seas (as exclusive economic zones (EEZs)). The commons is progressively being 'fenced-in', but the tragedy continues.

Although the fact that humans have the capacity for massive disturbance in marine environments has been known at least since the extinction of the Steller's sea cow in 1868, marine conservation did not become an international issue until the appeals in the 1950s and 60s by authors such as Rachel Carson (1962) and Jacques Cousteau's prolific output of books, films and television series, and organizations such as Greenpeace. As a result of these appeals and rising public awareness and concern, conservation efforts in the marine environment began in earnest with international conventions and programmes such as the London Dumping Convention, the 1973 MARPOL (International Convention for the Prevention of Pollution from Ships), the United Nations Convention on the Law of the Sea (UNCLOS) (1982) and the International Whaling Commission (1946).

However, despite these early conventions, the state of marine environments has continued to deteriorate significantly. Stocks of once globally abundant fishes such as cod, herring and tuna have in many instances become ecologically and commercially extinct. Over one million whales were harvested in a 100 year period, and only the eastern Pacific grey whale has recovered to near pre-exploitation levels. Elevated levels of pollutants are found in most marine species, even those living in the Arctic and Antarctic regions. Restaurants in California that serve tuna and certain other fish are required by law to post warnings to customers about the high levels of heavy metals in fish.

Tens of thousands of kilometres of coral reefs have bleached in recent years as a result of increased ocean temperatures, which may be aggravated by the addition of greenhouse gasses from the combustion of fossil fuels. Important breeding, feeding, mating and resting areas for migratory species have been affected by human activities. This is merely a brief summary of the continuing degradation of marine systems. Those interested in detailed accounts of the effect of human activities on marine environments should read the comprehensive works by Norse (1993), Thorne-Miller and Catena (1991) and the National Research Council (1995).

Unfortunately, as time goes by and new generations of people interact with the oceans, our human memories and expectations of the 'natural state' of the oceans also undergo progressive change. This generational change of perception of the state of the oceans has been captured in two memorable aphorisms from Daniel Pauly – 'The shifting baseline syndrome' (a term coined in 1995) and 'Fishing down marine food webs'

(Pauly et al, 1998). The first of these sayings captures the idea that although the oceans are progressively being degraded, each human generation comes to accept the degraded state as the norm. Nevertheless, whatever we currently have is still the majority of what the oceans have (or likely ever had – see below) and merits our determined conservation efforts. The second saying reflects the reality that fisheries resources of the oceans are returning smaller and smaller organisms; smaller members of species once dominated by larger populations, and smaller species once ignored or undervalued by fishers. The changing history of our views of the oceans and especially of the history of fishing fleets have been documented by Roberts (2007). We are surely and ever more rapidly reducing the biodiversity of our oceans by reducing the number of species, having an impact on habitats and their communities, and indeed destroying whole ecosystems.

What has been done to address the problems?

Humanity's response to our deteriorating marine environment has been predictably slow, reactive and piecemeal. Delays in responding to these environmental crises are exacerbated due to the fact that most marine environments are still viewed as a global commons resource, where there is little incentive to any one nation to address these issues, as problems must be solved at an international level. Early efforts at marine conservation were based on either the management of a single overexploited species (broadly referred to as single-species management) or the focus of attention on a particular environmental threat (e.g. a type of pollutant).

The discipline termed 'fisheries management' was developed to address the over-exploitation of single-species fish stocks. Fisheries management was initially based on the principals of maximum sustained yield (MSY), borrowed from forest management, which led to continued unsustainable harvest rates due to an inadequate understanding of the life histories of fish stocks and causes of variability in their populations. Recently, the traditional emphasis on management of single-species fish stocks has been changed to 'ecosystem-based management'. This has come with the realization that exploitation of single species has ecological and environmental impacts and implications well beyond the populations of the exploited species themselves, and with a renewed interest and appreciation of the structures and processes of the oceans themselves.

In nearshore areas, a similar holistic approach to management, termed 'coastal zone management', was initiated to try to integrate human activities with the goal of management and conservation of ecological systems. Coastal zone management reflected the realization that the abiotic and biotic components of marine systems were linked across spatial and temporal scales, and that any environmental change may have consequences throughout the food web.

More recently, another integrative approach, based on the conservation of defined spaces – marine protected areas (MPAs) – has been advocated as a way to protect the ecological functions of a community within a specified area such that the benefits of preserving an area may 'spill over' into adjacent areas. This book will attempt to deal with all three of these approaches to marine conservation, but with considerable bias towards the last.

How will this book address these problems?

This book is not about the litany of environmental problems in the oceans, nor is it primarily about management options and techniques. It is a book about marine biodiversity, marine conservation and ways to find solutions based on an understanding of the natural ecological hierarchies of the oceans. The purpose of this book is not to examine any one specific management construct – there are several other texts that address these topics – but to examine the various approaches to conserving marine biodiversity in light of the ecological structures and functions (processes) of marine environments. This book will provide the reader with a comprehensive canon of conservation frameworks that can be applied in all marine systems.

It is our belief that those responsible for the management and conservation of marine environments often overlook ways to conserve and manage marine environments, as they do not always fit within the traditional management systems they are familiar with. We centre this book on the conservation of marine biodiversity and its components, across the ecological hierarchy, rather than focus on any particular population, community, habitat or ecosystem. This is done because we feel that the practice of marine conservation, based on ecological principles, should be applicable from the global to the local level, and from ecosystems, through habitats and communities to individual cases of separate species and their populations.

The foundation of this book is therefore ecological in character, respecting the natural organization of the environment and biota of our planet. As Dobzhansky (1973) said of Charles Darwin: 'Nothing in biology makes sense except in the light of evolution.' To paraphrase this sentiment we could say that: 'Nothing in biodiversity conservation makes sense, except from the perspectives of ecology and the environment.'

What is biological diversity?

Biodiversity (biological diversity as coined by E. O. Wilson, 1988) is, put simply, the richness and variety of life in the natural world. The international *Convention on Biological Diversity* (United Nations Environment Programme (UNEP), 1992) defines biodiversity as 'the variability among living organisms from all sources, including … terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems'. The term 'biodiversity' therefore includes biological diversity and ecological diversity across the organizational hierarchy through genetic, species and ecosystem levels (see e.g. Gray, 1997).

The concept of biological diversity is widely misunderstood and variously interpreted, even within the scientific community. In its narrowest sense the term biodiversity is often used synonymously with species diversity – but it is far more than this. As defined above, the term 'biodiversity' includes the diversity of genes, species and their populations, communities and ecosystems, as well as the dynamic processes that change them and their environments. The rationale for such a broad definition is based on the realization of the basic hierarchical organization of nature, and that no level of the hierarchy can exist without the support and interactions of all the other levels. For example: species cannot thrive without suitable habitats within which to live, habitats cannot exhibit any constancy of conditions without the ecosystem level processes that maintain them, and so on across the whole hierarchy of ecological and environmental interactions. In the broadest sense, we should perhaps speak of ecological diversity and/or environmental diversity.

It has been suggested that the concept of biodiversity is too 'all-encompassing' because it represents the sum total of all living things and their planetary life-support systems. In other words the term has become so general and all-encompassing (because it includes everything) that it has become meaningless; the currency has become debased. We do not agree, and we shall use the term in its broadest sense. Perhaps the most significant aspect of the concept of biodiversity is that it allows its components to be identified and analysed from spatial, temporal and ecological perspectives. This permits a hierarchical context and an approach to environmental and ecological problems that we might well not otherwise appreciate. The full significance of this should become apparent in subsequent chapters.

Why should marine biodiversity be protected?

Biodiversity is really the value of our biosphere and its environment, but because biodiversity encompasses 'everything' its value and benefits are not easily defined or categorized. However, now that Marshall McLuhan's 'global village' has become a reality, we need to categorize the components of biodiversity and approach their conservation in a systematic and responsible way. We can then recognize 'who should do what – and why'.

The reasons for protecting biological diversity are complex and encompass environmental,

Box 1.3 A brief history of marine biodiversity conservation

While many indigenous cultures, particularly Pacific island cultures, efficiently managed marine resources using many of the same approaches (e.g. closed areas, catch and size limits) used today, modern marine conservation is relatively new and has traditionally lagged behind terrestrial conservation in nearly every aspect. This is primarily due to the difficulty in understanding and measuring human impacts to marine systems relative to the terrestrial realm combined with the reality that humans generally have less of a connection with marine environments and therefore are more difficult to engage on marine conservation issues. This situation has led to the following perspectives/circumstances over the past several centuries:

- 1800s: Marine resources are thought to be inexhaustible.
- 1900s: Key fisheries are thought to be inexhaustible.
- 1960s: Major fish populations decline; traditional fishing communities break down; ecosystems deteriorate.
- Current: Ocean governance is fragmented; diverse impacts are not managed in a coordinated manner; human-induced ecosystem shifts have occurred; oceans are managed independent of the terrestrial environment.

However, marine biodiversity conservation is beginning to catch up to terrestrial conservation efforts. While many conservation efforts have been led by individual nations (e.g. Australia and the Great Barrier Reef) a number of key international laws and conventions have begun to recognize the importance of marine conservation and management and include the following:

- 1972: Stockholm Declaration commits signatories to conservation of biodiversity, sustainable use of marine environments and the use of the maximum sustained yield concept.
- 1982: UN Convention on the Law of the Sea commits signatories to conserving fish stocks, preventing introductions of alien species, and considering species interactions in management.
- 1992: Rio Declaration commits signatories to applying the precautionary approach, marine protected areas, and use of traditional knowledge in decision-making.
- 1992: Agenda 21 commits signatories to the conservation of fish stocks, application of integrated coastal zone management, consideration of climate change, and financial incentives to conserve.
- 1995: UN Agreement on Straddling Stocks commits signatories to the more cooperative management of migratory fish stocks and stocks with broad geographic ranges.
- 1995: FAO Code of Conduct commits signatories to end destructive fishing practices, adopt selective fishing gear, consider local marine users/communities in decision-making and support fisheries research.
- 2001: FAO Reykjavik Declaration commits signatories to applying the ecosystem approach to fisheries management.
- 2002: World Summit on Sustainable Development commits signatories to honour previous agreements as well as to coordinate and better cooperate on marine agreements.

Significant progress has been made with respect to conserving marine environments. Currently, nearly every commercial species of significance has some type of science-informed management plan developed across jurisdictions that is often based on the ecosystem approach to fisheries (Chapter 13). Whether these plans are adhered to by fishers and political institutions, and whether they are sufficient to prevent over exploitation of fish stocks, is another matter. In addition, nearly 1 per cent of the ocean's surface is captured by some type of protected area designation; however, many of these protected areas continue to allow extractive activities. Many national and international legislative tools are now in place to assist with marine conservation and management efforts; however, without the political will and public pressure to implement these tools, the condition of many marine habitats and their communities will continue to decline.

(Christensen et al, 2007; Guerry, 2005).

economic and social benefits (e.g. Beaumont et al, 2007), though it is fair to say that stronger rationale, whether scientific, socio-economic or ethical should be developed (see e.g. Duarte, 2000). The rationale for protecting biodiversity falls into several major categories which can be summarized as: Intrinsic Value, Anthropocentric Value (ecological goods and services for humans) and Ethical Value. Some of these reasons are summarized here.

Intrinsic Value This is a rather contentious issue – that is, that the components of biodiversity, species and natural systems have their own worth independent of human needs or considerations. For most ecologists and environmentalists, this has become largely a philosophical issue unless related to the concept of ecological functioning and how ecosystems 'work'.

Intrinsic Value reconsidered We shall explicitly consider the concept of the 'value' of marine biodiversity and how marine environments can be ranked for conservation purposes, in such terms in Chapter 15.

Anthropocentric Value – vulnerability Loss of diversity generally weakens entire natural systems; every species can be considered to play a role in maintaining healthy ecosystems upon which humans ultimately depend. When simplified by the loss of diversity, ecosystems become more susceptible to natural and artificial perturbations, or may change completely in state (e.g. on the Scotian Shelf, Canada, removal of key predators combined with effects of bottom trawling have completely changed the character of an entire ecosystem (Frank et al, 2005)). Species listed as endangered and threatened include several marine mammals (Hoyt, 2005); many of them are key to ecosystem functioning and are also valuable from an economic, ethical or aesthetic perspective.

Anthropocentric Value – renewable resources Biological diversity represents one of our greatest untapped natural resources and future potential. Our marine areas contain innumerable raw materials that could provide new sources of food, fibre and medicines, and new discoveries continually contribute to scientific and industrial innovations. The pharmaceutical potential of thousands of yet-to-be-discovered marine products to provide life-saving or commonly used drugs is an example of the almost untapped potential of our oceans for sustainable economic use. Nature has repeatedly proved to be a much better chemist than mere mortals – over 60 per cent of all anti-tumour agents and anti-infective agents introduced worldwide over the last 15 years have had a natural product structure in their background (Newman and Cragg, 2007). Only over the last couple of decades has the immense potential of the marine environment as a source of undiscovered chemical structures begun to emerge. For example, recent research indicates the synthesis of a protein produced by mussels (which in nature helps the shellfish stick to rocks) may be useful to close wounds that would otherwise require stitches. Given that we know so little about our marine resources, the potential for life-saving or beneficial pharmaceuticals is enormous and is expanding every year.

Anthropocentric Value – non-renewable resources The socio-economic value of non-renewable resources has historically over-ridden concerns for the natural environment. Hopefully with changing environmental values, and the application of the concept of ecosystem-based management, we shall progressively see a reconciliation of biodiversity and resource values.

Anthropocentric Value – ecosystem goods and services Humans benefit from natural areas and depend on healthy ecosystems. The natural world supplies our air, water and food, and supports human economic activity. Much of the world's protein comes from marine sources, and MPAs are an important mechanism to enhance commercial fisheries species. Marine fisheries around the world are clearly heavily overexploited and not sustainable. The establishment of protected areas is one of the few positive steps taken that reverse this trend. The growing discipline of 'natural capital valuation' is beginning to document the 'goods and services' provided to humans by the components of biodiversity of the natural world, including the attributes that lead to aesthetic and recreational values.

Anthropocentric Value – 'insurance' From an ecological stance this is perhaps the most fundamental and important concept. We still have much to learn about the oceans. Their depths are literally as unknown to us as the far side of the moon. Ultimately, we do not know the full environmental and ecological significance of the components of marine biodiversity or how they function in concert. Protection of the oceans can therefore be regarded as a sort of insurance policy; as we destroy its components we cannot predict the consequences. The Precautionary Principle (see Chapter 13) advocates a willingness to accept credible threat in advance of hard scientific proof. Although the principle has been widely adopted, first by the European Union, it has not been generally or seriously implemented in the oceans – even in the face of hard scientific evidence.

Three fundamental things are clear. First, a planet containing the oceans without land is perfectly viable; but a planet consisting of land without the oceans is not viable; the oceans regulate the homeostatic mechanisms of our world. Second, as we progressively degrade natural communities and ecosystems the world reverts to its more primitive microbial dominated systems; humans are unlikely to vandalize a world to the extent that it does not support life, but we could see a world that does not support a wealth of species – including our own. Third, we simply do not know how far we can degrade natural habitats and their communities before effects are irreversible; in some cases parts of the oceans seem already to have reached 'alternative stable – and undesirable states'. Conservation ecologists frequently invoke the concept of 'ecological integrity', although in the oceans its real meaning is awkward and not clearly understood (see Chapters 16 and 17).

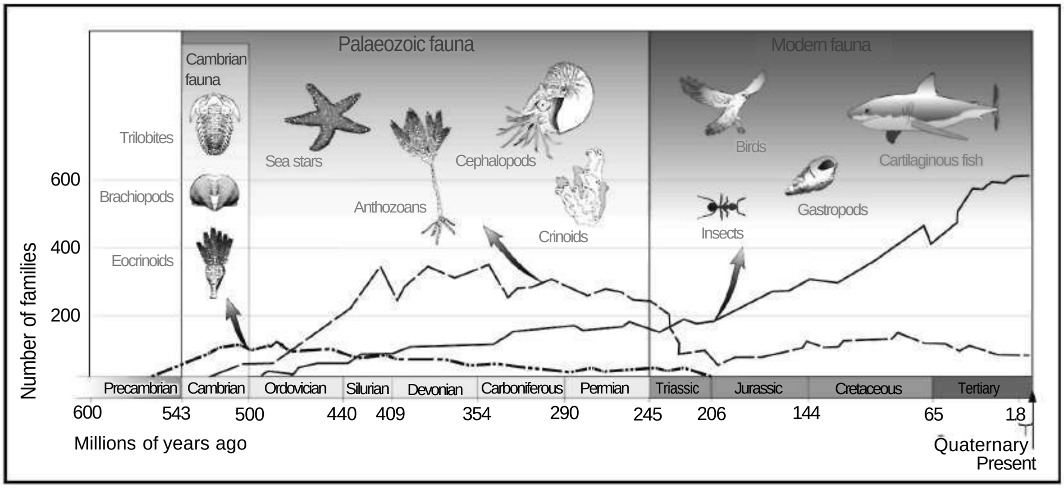
Ethical Value – nature and responsibility The argument is made that humans are simply a part of nature and that we should not endanger our own environment. We humans are the only species on the planet that has the capability of driving many others to extinction. Environmental ethicists also stress that we have a moral responsibility to protect the environment and the other species on our planet. The concept of environmental stewardship for example is a fundamental part of Judeo-Christian religions.

Variation in biodiversity over geological and historical time

The taxonomic diversity on our planet has varied greatly in the past (see Signor, 1994; Sepkoski, 1997), but may presently be at an all-time high (see Figure 1.1), possible because of the greater spatial separation of the land masses and the abundance of shallow seas and consequent high habitat diversity (as a function of spatial heterogeneity – see Chapter 8). However, the rate of species extinctions is probably also at an all-time high (with the exception of mass extinction events) due to human environmental disturbances. We therefore seem to be living in paradoxical times, currently experiencing a bounty of the greatest species richness but also annihilating them at the greatest rate!

The process of evolution occurs in both the biological and inorganic world, and in the terrestrial and aquatic environments. The lesson of evolution is that all forms of life on earth change as the environment itself changes. Individual species (including humans) must either adapt to these changes or become extinct. As far as we know, the human species is the only one to have caused the extinction of many other species.

As a terrestrial species, our major pre-historical and historical environmental effects have been on land and in freshwaters. However, human effects on the oceans are now substantial and growing; they range from local to global in scale. No part of the oceans is now removed from human influence. Efforts to conserve our oceans are now vital, not just for the benefit of local human environmental and socio-economic health, but because of global concerns.



Source: Redrawn from Sadava et al, 2006

Figure 1.1 Variations in taxonomic diversity on earth over geological times

The components of marine biodiversity

Human beings classify things – either explicitly or implicitly. Classification of things seems to be an inherent human characteristic, necessary to codify the world around us – its features, its changes, its dangers, its resources. This propensity to classification permeates society as well as science. In science it leads to the classification of sub-atomic particles and the periodic table of elements. In biological sciences it led to Linnaeus's system of naming and classifying plants and animals (the *Systema Naturae*, 1758) and to Darwin's theory of evolution by natural selection. It is impossible to image modern biology without these foundational methods of organizing and categorizing the relatedness of life forms on the planet.

In a concept as large as biodiversity, similar organizational frameworks are also required. We should capitalize on the human requirement for classifications in order to understand the nature of biodiversity. A matrix of the components of marine biodiversity (see Table 1.1) has been proposed by Zacharias and Roff (2000), wherein the compositional levels of the hierarchy and corresponding structural and functional components are indicated. This framework is a marine adaptation of a hierarchical ecological framework based on the work of Noss (1990) that separates biodiversity into compositional, structural and functional attributes at the genetic, population, community and ecosystem levels of organization. Classifications of components can in fact be made at any level within the ecological hierarchy and in various ways. Such classifications help us to develop perspectives, for example on what exists, what has been degraded or lost (and to what extent or in what proportion), where priorities should be assigned, what is more sensitive, vulnerable and so on.

In Table 1.2 we expand on the matrix of Table 1.1 to show some more specific components of marine biodiversity. It is important to realize here that the Structural components are time-independent – that is, they have formal physical 'dimensions' L^3 or M (mass) only. The Functional or Process components of biodiversity are changing over time and therefore have dimensions of $M.T^{-1}$ or just T^{-1}. This sort of tabulation is not meant to be an exhaustive or inclusive listing of components, but rather it is an indication of what the components of marine biodiversity actually comprise at each of the levels of organization of the ecological hierarchy. It is a checklist

Table 1.1 Compositional, structural and functional attributes of biodiversity proposed by Zacharias and Roff (2000) for marine environments, contrasted to the terrestrial framework of Noss (1990)

Compositional		Structural		Functional	
Noss (1990)	Zacharias and Roff (2000)	Noss (1990)	Zacharias and Roff (2000)	Noss (1990)	Zacharias and Roff (2000)
Genes	Genes	Genetic structure	Genetic structure	Genetic processes	Genetic processes
Species, populations	Species, populations	Population structure	Population structure	Demographic processes, life histories	Demographic processes, life histories
Communities, ecosystems	Communities	Physiognomy, habitat structure	Community composition	Interspecific interactions, ecosystem processes	Organism/habitat relationships
Landscape types	Ecosystems	Landscape patterns	Ecosystem structure	Landscape processes and disturbances, land-use trends	Physical and chemical processes

of what biodiversity is that we can use as a reference for conservation studies and planning. In later chapters we shall expand on the contents of this table, and separately consider the relevance of each of these levels of the marine biodiversity hierarchy and their components.

Some preliminary definitions and remarks are in order here. Within the ecological hierarchy we proceed from genes, through species and their populations to the community level (Table 1.1); all these levels describe strictly biological components. Communities are indicative of particular kinds of habitats (which are defined in terms of their abiotic environmental characteristics), and sets of habitats and their communities comprise ecosystems. Habitats are thus abiotic entities, while ecosystems are compositely biotic and abiotic in nature. Note that the terms habitat and ecosystem are sometimes used interchangeably. Our preference is to use them in their original and classical meanings. In summary, by using the ecological hierarchy we are already considering a hybrid system of classification employing both biotic and abiotic (geophysical) features. Note also that other levels of a hierarchy could be interpolated, such as habitats or landscapes.

The landscape level of ecology (often inserted between habitats and ecosystems) can also be described either in abiotic or biotic terms, or in some combination of both. The equivalent term in marine conservation 'seascapes' is slowly coming into general use, sometimes as the synonym 'marine landscapes' to describe coastal features. A terrestrial landscape typically comprises some set of habitats of variable type, within a recognizable landform (valley, hill etc.). Although the term seascape should be analogous, in fact we shall generally use it in a more restrictive sense to mean an array of a particular kind of habitat type (see Chapter 5).

Marine landscapes – seemingly at first an odd or compromise term, is in fact quite appropriate where it is defined primarily by local or regional topography (landform). Where described primarily by the characteristics of the water column the term seascape is more appropriate. The marine conservation community has not settled on this level of terminology and we shall use both.

The marine environment may also be defined and described in spatial terms. Here the range is from global biogeography to genes. Terms such as marine provinces, ecoregions, geomorphic units, representative areas and so forth are used, and their meanings and usage will become clear in later chapters. In order to define these units of the biosphere we make use of some combinations of biotic and abiotic data,

Table 1.2 An expansion of the marine biodiversity framework from Zacharias and Roff (2000), showing attributes of structures (statics) and processes (function or dynamics) arranged under the population, community and ecosystem levels of organization

Genetic		Species/ Population		Community		Ecosystem	
Structures	Processes	Structures	Processes	Structures	Processes	Structures	Processes
1. Genetic structure	1. Mutation	1. Population structure	1. Migrations	1. Community structure	1. Succession	1. Water masses	1. Ocean currents
2. Genotypes	2. Genotype differentiation	2. Population abundance	2. Dispersion	2. Species diversity	2. Predation	2. Temperature	2. Tidal currents
3. Fitness	3. Genetic drift	3. Distribution	3. Retention	3. Species richness	3. Competition	3. Salinity	3. Physical disturbances
4. Genetic diversity	4. Gene flow	4. Focal species	4. Migration/ counter drift	4. Species evenness	4. Parasitism	4. Water properties	4. Gyres
5. Stock discrimination	5. Natural selection	5. Keystone species	5. Growth/ production	5. Species abundance	5. Mutualism	5. Boundaries	5. Retention mechanisms
	6. Inbreeding	6A. Indicator species – condition	6. Reproduction	6A. Representative communities	6. Disease	6. Depth/pressure	6. Pelagic–benthic coupling
	7. Non-random mating/ sexual selection	6B. Indicator species – composition	7. Recruitment	6B. Distinctive communities	7. Production	7. Light intensity	7. Entrainment
	8. Directional selection	7. Umbrella species		7. Biome types	8. Decomposition	8. Stratification	8. Biogeochemical cycles (inc. nutrient dynamics/ energy flow)
	9. Stabilizing selection	8. Charismatic species		8. Biocoenoses		9. Bottom topography	9. Seasonal cycles (physical and biological)
	10. Disruptive selection	9. Vulnerable species		9. Species–area relationships		10. Substrate type	10. Productivity
	11. Micro-evolution	10. Economic species		10. Transition areas		11. Geophysical anomalies (inc. frontal systems)	11. Hydrosphere–atmosphere equilibria
	12. Genetic erosion	11. Phenotypes		11. Functional groups		12. Wave exposure	12. Hydrosphere–lithosphere equilibria
	13. Speciation	12. Population fragmentation		12. Heterogeneity		13. Patchiness	13. Eddy diffusion/ turbulence/internal waves
	14. Macro-evolution	13. Meta-populations		13. Endemism		14. Nutrients	14. Mixing/stabilization
				14. Alternate stable states		15. Dissolved gasses	15. Upwelling/ convergences
				15. Symbioses		16. Anoxic regions	16. Divergences
				16. Biomass			17. Ecological integrity
							18. Erosion/ sedimentation
							19. Desiccation

Box 1.4 Definitions of some terms used throughout the book

A **structure** is any measurable quantity whether biotic or abiotic. Structures have no dimension of time, but they change over time and space as the result of physical and biological processes.

A **process** is any quantity, physical or biological, that varies over time, causing changes in structures. All processes have dimensions of time.

By **environment** we specify the sum total of all external influences (physical, chemical and other biological) on living organisms.

By **ecology** we mean the study of organisms in relation to their environment.

We shall use the term 'ecological hierarchy' to mean the array of biological entities, both structures (instantaneously observable quantities) and processes (or functions – the rates at which observable quantities change). This hierarchy spans biological and physico-chemical environmental structures and processes from the genetic to the ecosystems level.

The terms **genetic, species and population** are clear and we shall use these in conventional ways.

The term **community** is used in many senses. Most biologists accept that it is a vague term, and want to keep it this way. Originally it meant a group of species that interacted (either actually or potentially) in some ways. It still means this, although in practice, except in the very simplest communities, the specific ways in which members of communities actually interact at any given time is not known. A more neutral term is an 'assemblage' of species. Here we simply imply that a set of species are generally found to co-occur.

A **habitat** is a physically defined region of the environment, usually accepted as housing a defined community type. It is usually more straightforward to recognize and map habitat types than to define the communities associated with them.

Landscapes is a term used in terrestrial ecology to define regions of the earth that contain sets of habitats, generally of somewhat different types. Landscapes are therefore analogous to geomorphological features (see Chapter 5).

The corresponding term in marine ecology would be **seascapes**. This is a relatively new term that is not yet widely used. It is used here to define a particular set of habitats of similar type. Seascapes are therefore NOT equivalent to geomorphological features.

The term **ecosystem** is a useful one, but difficult to define. In its original sense, as applied for example to a lake, the intent of the term was clear. It was used to describe a 'chunk' of the environment that contained several natural communities of organisms, and that was more or less clearly circumscribed. In the marine environment, although the term 'ecosystem' is frequently used, because of the continuous nature of the medium (as opposed to the discontinuous nature of lakes for example), ecosystems are not readily defined (except somewhat arbitrarily). We shall, however, use the terms 'ecosystem structures' or 'ecosystem level processes' as more or less synonymous with habitat structures and processes.

including data on the physiography and oceanography of the marine environment. Direct information on the distribution of marine biota is often sparse. We therefore must have recourse to other abiotic data, which act as surrogates or indicators of expected or predicted distributions of the biota themselves. These characteristics may be described as either 'enduring' (predominantly physiographic) or as 'recurrent' (predominantly oceanographic).

Genetic level

The genetic variation in a population, both within individuals and among the members of a population, ensures that the vicissitudes of the environment can be met by at least some of its members. It ensures that Natural Selection can operate on the inherent variation within and among species; if a population consisted entirely of a single clone with no genetic variation, then that entire population is in danger of mass extinction in the face of some environmental change to which it cannot adapt. The genetic level of organization in fact contains vast amounts of yet untapped information that is becoming of fundamental importance to marine conservation, as we shall examine in Chapter 10.

Species level

Of all the species known to science, about 80 per cent are terrestrial, but there are more orders and phyla in the sea. In fact, all phyla of animals are found in the sea, a majority of these in benthic environments, and one third of all the phyla are exclusively marine. If plants and protists are also considered, then at least 80 per cent of all phyla include marine species. In addition, the relative abundance of marine species may be greater than presently considered, since more marine species are unknown (Thorne-Miller and Catena, 1991). The distribution of species diversity among taxa is very uneven – some taxa such as the arthropods are very species-rich, whereas others contain few species. Biologists debate why this should be so in terms of the 'adaptability and success' of fundamental body plans.

At the species level, we frequently seem to make the implicit assumption that some species and their habitats are more valuable than others. This presumably was – and may still be – the rationale for conservation efforts directed at individual species. But how can we or should we make such decisions? Should we recall the famous Orwellian dictum: 'All animals are created equal – but some are more equal than others'? In fact (in Chapter 9) we will show that there are several ways in which we can rationalize that we should pay disproportionate attention to selected species.

Communities and habitats level

There are no clear answers as to why species are distributed as they are among higher taxa, but what should we expect from species diversity distribution among communities and their habitats? Why should some habitats and their communities be richer in species than others? We shall make a preliminary exploration of some of these questions in Chapter 3, for example in comparisons of plankton and benthos. In fact reasons for higher or lower species diversity within communities are not well known though theories and explanations abound. Species diversity in communities is related to a variety of factors that will be explored, primarily in Chapters 6 and 8.

Ecosystem level

At the habitat or ecosystem level and above, we encounter an array of considerations that need to be disentangled for conservation purposes. At the level above (or including) that of ecosystems lies the discipline of global biogeography. This is a discipline historically older than biological conservation, where interest has typically centred on describing distributions of particular individual taxonomic groups such as echinoderms, molluscs or fish. In this book our interest is less in the particular taxonomic groups themselves, and more in other directions. Specifically we shall look at ecological boundaries and how they relate to changes in the species composition of communities irrespective of taxonomic groups – that is, how we can classify and define the distributions of whole arrays of biota. Secondly, from global to regional and local scales, we shall examine patterns and factors underlying the distribution of the complement of species – species richness.

The overall intention then is to classify marine environments from the global to the local level so as to recognize and define their distributions and patterns, and to facilitate analysis of their biodiversity components so that marine conservation initiatives can be undertaken in a coordinated fashion and according to ecological principles.

Some marine ecosystem types have been grossly degraded by human activities, especially in the coastal zone. Other ecosystem level processes – especially at the global scale, for example ocean circulation – have traditionally been seen as independent of human effects. We are finally realizing that even this is not true as the effects of global warming are felt on ocean circulation!

Threats to marine biodiversity

There are potentially many ways to collate and discuss threats to marine biodiversity, but threats can be broadly categorized as a result of overharvesting, pollution, habitat loss, introduced species and global climate change (see e.g. NRC, 1995; Gray, 1997). The following sections provide a brief discussion of these impacts on the marine environment and indicate how this book intends to address these threats. Many marine areas have a range of biota rivalling or exceeding that of tropical forests. However, the diversity of life in our oceans is now being dramatically altered by rapidly increasing and irreversible human activities. Although there are differing views of present and potential threats to coastal and marine biodiversity, those shown in Table 1.3 are among the most important.

Overharvesting

The unsustainable harvest of marine populations is perhaps the most serious threat to marine environments worldwide. Overharvesting is not a new phenomenon in the oceans. Many traditional cultures either removed the available species from their local marine environment and moved onto harvesting other areas, or had to develop some methods of regulating the timing and amount of harvest from certain areas in order to avoid overexploitation of populations. The advent of the industrial revolution resulted in the increasing mechanization of fish harvesting so that species such as large whales and offshore pelagic fish – that were previously difficult to catch – were now accessible in a commons environment which was owned by no one. Over one million whales have been harvested, and most species have been reduced to levels where they are considered endangered or threatened. Most populations of palatable fish stocks have been seriously depleted, and currently there is evidence that humans have fished down food webs and will continue to do so (e.g. Pauly et al, 1998). This book is not primarily about fisheries. But the vital issue of how to link fisheries management with broader marine conservation objectives through ecosystem-based approaches (e.g. Gislason et al, 2000; Hughes et al, 2005), is considered in Chapter 13.

Table 1.3 Examples of threats to marine biodiversity

Risk or speed of degradation of biodiversity	Threatening process
High	Physical habitat destruction (e.g. reclamation, dredging)
	Blast fishing using explosives, *meting*[1] (either can annihilate a coral reef)
	Toxic pollution (e.g. chemical spills)
	Chemical fishing (e.g. cyanide)
	Introduction of exotic organisms
	Loss of genetic variability
	Biological invasions
	Overexploitation/overfishing
	Bioaccumulation of noxious materials (e.g. heavy metals)
	Indirect pollution (pesticides, herbicides in runoff)
	Disease/parasite infection
	Depletion of spawning sites
	Sea dumping of dredge spoil
	Incidental take/by-catch
	Destruction of adjoining watersheds
	Impacts of adjacent land-use practices (e.g. aquaculture)
	Effluent discharge (sewage, pulp/paper)
	Natural events (cyclones, tsunamis)
	Direct marine pollution, ocean dumping
	Downstream impacts from dams, dykes, etc
	Net/debris entanglement
	Siltation
	Noise pollution
	Toxic blooms/red tides
	Thermal pollution
	Climatic change – rising sea temperatures
	Sea-level rise
	Salinity changes
Low[2]	Indigenous take

[1] *Meting* is an emerging threat that involves the indiscriminant removal of all organisms from reefs using metal crow bars to rip away coral cover to harvest species such as abalone and clams.

[2] The 'high–low' scale on the left side of this table is approximate only; it seeks only to indicate that some threatening processes have a higher risk and/or speed of impact on marine diversity than others. Moreover the relative order of the various threatening processes on this scale is open to conjecture.

Pollution

There is no question that pollution from a variety of sources has affected every marine system on earth. Indigenous human populations in

Arctic areas are the most contaminated people on earth, as a result of ingesting marine fish and mammals which bioaccumulate toxins due to their high trophic levels. It was generally assumed that pollutants reached the oceans primarily in runoff from rivers. In some coastal areas this will indeed be the case, but overall transport of pollutants through the atmosphere to the oceans is more important. The types and lists of pollutants appear endless, including artificial radionuclides, petroleum hydrocarbons, chlorinated hydrocarbons, metals, carcinogens, mutagens, pesticides, excess nutrients causing nuisance and toxic algal blooms, endocrine disrupters, physical debris and so on. The persistence and longevity of pollutants in the marine environment, and their ecosystem-level effects on marine biota and ultimately humans, are of growing concern. Nevertheless, again, this book is not primarily about pollutants; it is about the components of biodiversity that may be affected by various kinds of pollutants. This is the backdrop against which their impacts can be judged.

Habitat loss

Habitat loss is probably the most serious threat to biodiversity in terrestrial environments due to the removal of larger vascular vegetation on which many species depend for food and shelter. Loss of marine habitat is primarily a concern in coastal nearshore and intertidal marine environments. Increasing pressure in coastal systems has come from a combination of: shipping – with attendant infrastructure and transportation; other construction and modification of natural coastlines; fishing; recreational activities; and increased land runoff – including nutrients and suspended solids. The types of habitats in these areas which can be ‘lost’ include marine macrophytes (kelp), mangroves, sea grasses, corals and other biotic communities (e.g. sponges, sea pens, sea fans, aphotic corals) as well as abiotic habitats, such as intertidal and estuarine mud flats and other areas which are dredged or subject to dumping. Habitat loss in deeper marine environments and the pelagic ocean is a more vague construct as these habitats are primarily composed of either oceanographic (e.g. currents, gyres, fronts) or physiographic (e.g. seabed composition) structures and processes which are more resilient to human activities – or less immediately impacted. Loss of marine habitat is significant not only from an ecological perspective, but also increasingly from a socio-economic perspective. The interaction of human effects and natural marine processes is most evident in coastal waters, where strategies to prevent habitat loss or mitigate effects and restore habitats are encompassed in (integrated) coastal zone management initiatives (see Chapter 11).

Introduced species

Species introductions (also termed invasive, exotic and non-native species) have probably been occurring for as long as humans have used the oceans for exploration and trade. There is evidence that many species we believed to be native are now thought to have been introduced through marine transportation prior to the industrialized era. Transport in the ballast water of ships appears to be the main mode of travel, and impacts are generally observed mainly in coastal waters and estuaries. While the introduction of larger species such as the green crab (*Carcinus maenas*), the alga *Calaupera taxifolia* and the comb ‘jellyfish’ *Mnemiopsis leidyi* has been well publicized, most species introductions are less obvious, and are found in the phytoplankton and zooplankton. A single 24-hour study in Washington State, USA found over 110 non-native species. Some of these invasive species can have dramatic local socio-economic effects, with different species of jellyfish having major impacts on fisheries and even coastal human recreation. Outbreaks of jellyfish have now been reported from locations around the world, probably caused by a combination of species invasions, overfishing leading to food web disruption and local water temperature increases.

Global climate change

There is no doubt that the earth’s climate changes over time and that these cyclical changes occurred long before humans became the dominant species on the plant. Global climate changes have been responsible for mass extinctions in the past and the earth's climate will continue to vary, resulting in future mass extinctions. Sea levels have been known to deviate up to 85m during the Quaternary period, which inhibits the evolution of established marine communities in coastal and shelf environments. Humans have also been shown to have an impact on global temperatures, and since the 1980s there has been considerable debate on separating out the natural and anthropogenic contributions to climate change. Human activities that affect climate change include the release of CO_2 through the burning of fossil fuels, and large-scale deforestation – which lowers the total amount of CO_2 removed from the atmosphere. Changes in water temperatures and changes in coastal salinities caused by changes in insolation, evaporation and rainfall, and land runoff patterns will result in the resetting of biogeographic boundaries. Some species will extend their ranges while others will contract – often with unpredictable consequences for regional community composition. Regional conservation strategies and practices may in turn therefore require incorporation of climate change scenarios, necessitating a clear understanding of changing ecological relationships.

Approaches to address threats to marine biodiversity: Marine conservation

The term 'marine conservation' has come to mean at least two rather different things. The dominant sense in which we shall use the term in this book is to mean *preservation of the components of marine biodiversity*, including their structures and processes, in a natural state. The key words here are 'preservation' and 'natural state'. Preservation of marine biodiversity entails the establishment and management of MPAs, and removing (or severely restricting) human influences on them. This will be the major theme of this book. Some would argue that natural states or pristine environments no longer exist, or that such conservation is no longer attainable in the face of human manipulations of the planet's resources. We shall leave this argument in abeyance, despite the high rates of species extirpations both on land and in the sea, and argue that we must make efforts to systematically conserve what we have.

A second sense of the term marine conservation is *the sustainable use of biological resources and ecosystems*. However, as we shall show, it has become evident that such conservation – by sustainable exploitation – still benefits greatly from the establishment of protected areas. Marine conservation has had a long history in many countries, much of it unrecorded and unsuccessful until recently. Not until the advent of scientifically controlled MPAs, which closed certain areas of the oceans to human activities, did the effects of marine conservation actually become apparent. The concept of zoning of the oceans (e.g. Agardy, 2010) – that the oceans are no longer to be conceived as a 'commons' or a 'free-for-all' but that human activities in the oceans must now be regulated – has now come of age. In part this has become feasible because of new technologies. Only in the last two decades has it become possible to know not only where everyone on the oceans actually is, but also – to a considerable extent – what they are doing.

Fisheries management by managing the behaviours of both suppliers (fishers while at sea) and consumers (in terms of product choices) have now become effective options. Even in the coastal zone, where effects and consequences of human actions are individually visible, management has been largely ineffective until education and public awareness have forced changes.

Marine protected areas (MPAs)

Marine conservation can be regarded as a multifaceted discipline that seeks to address both preservation of marine biodiversity and the regulation of use of exploited resources. The emphasis in this text is on the analysis of the components of marine biodiversity, and on marine protected areas and their role in preservation of marine biodiversity. Marine protected areas come by several names in the literature, but we shall refer to all marine protected areas by the generic term of MPAs.

It has been argued, several times, that if we could only restrict the spatial extent and intensity of fishing activities (e.g. bottom trawling), plus control the flow of pollutants to the oceans, we should not need to adopt any further form of marine conservation. In theory this may perhaps be a rational argument, but until a global consensus on such management of the oceans might be reached, the single most effective means of simultaneously preserving biodiversity and enhancing fisheries appears to be to locally establish protected areas – MPAs – where human activities are regulated.

Establishment of MPAs is not the only thing we need to do to accomplish sustainable management of the oceans. However, it has been repeatedly shown that MPAs are effective not only in protecting the various habitats of the marine environment – that is, they have a dominant role in marine preservation – but that they can also contribute significantly to the conservation of individual species – primarily of fish. That is, they have an important role in the sustainable exploitation of biological resources.

Sustainable exploitation of biological resources in the oceans – primarily through fisheries – is now generally considered to require BOTH the establishment of restricted fishing areas and the regulation of stocks through catch quotas. Marine conservation also entails protection of the coastal zone from effects of land-run-off, for example soil erosion and eutrophication. At least three things are therefore required for effective marine conservation: MPAs, pollution control and regulation of fisheries (both in terms of catch quotas and gear activities). Marine protected areas can be therefore thought of as a necessary but not a sufficient contribution to integrated marine conservation (e.g. Allison et al, 1998). MPAs are only one tool in a potential arsenal of approaches to marine conservation, but they are an essential tool. We can think of MPAs as a series of modern-day 'Noah's Arks' for at least the interim protection of selected areas.

How we select MPAs as a planning tool for conservation of the components of marine biodiversity, without being purely arbitrary, is a major theme of this book. MPAs are very effective in conserving certain types of habitats and certain types of biological communities, particularly if they have been chosen using a science-based representative framework. For example, coral reefs are particularly well suited to protected area status because they are physically defined areas harbouring a characteristic diversity of species (e.g. Thorn-Miller and Catena, 1991). Other benthic communities may also receive adequate protection from an MPA, but pelagic communities are less amenable to such methods. Similarly if MPAs are likely to be significantly influenced by impacts originating outside their boundaries (e.g. pollution from mainland runoff), then an individual MPA may have only limited benefits.

The effectiveness of the protection afforded by an MPA, or a set of MPAs, to marine animals and plants that occur within it is a critical concept to evaluate if conservation initiatives are to remain credible (see e.g. Leslie, 2005). Effectiveness of an MPA will depend on several considerations, including:

- The function of an MPA, e.g. Representation (Chapter 5) or to protect selected species, e.g. Distinctive areas (Chapter 7).
- The size of the area protected (see Chapter 14).
- The activities that are restricted and allowed within the MPA boundaries. This is the concept of zoning recently addressed by Agardy (2010).
- The MPA designation and whether it restricts polluting activities that occur outside the MPA but that threaten life within the MPA.
- Its ecological integrity, in terms of source–sink dynamics and recruitment to other MPAs within a network (see Chapters 16 and 17).

In protecting and conserving marine biodiversity it is important to recognize that biodiversity can be understood, conserved and managed at a range of spatial and temporal scales. Biodiversity occurs at the scale of large marine ecosystems, such as major oceanic ecosystems, and may be defined by large-scale oceanographic processes (i.e. currents and upwellings) and by trophodynamics, as well as coastal and oceanic physiography and topography. Biodiversity also occurs at other scales, whether considered as communities (see Chapter 6), habitats or specific sites. At these finer scales, patterns in biodiversity may be dominated by small-scale physical processes such as the type of substratum, cyclones, storm events, tidal range and changes in wave exposure, or by biological processes such as competition and predation. All these aspects are discussed more fully in subsequent chapters.

The importance of scientific knowledge of the oceans

In the face of human impacts on the oceans, the fundamental importance of scientific knowledge should be apparent. The necessity for conservation of the marine environment, its structures and processes, has never been more pressing. The sad reality is that we still know very little – in systematic terms – about the marine realm, its global significance and the impacts of human activities upon it.

> *Despite their importance to us, humankind is destroying marine populations, species and ecosystems. Leading marine scientists have concluded that the entire marine realm, from estuaries and coastal waters to the open ocean and the deep sea, is at risk.* (Norse, 1993)

Fortunately, several recent initiatives, including the Census of Marine Life (CoML) are now seeking to improve our knowledge of biodiversity in the oceans, and thus provide the basis for understanding the causes and consequences of changes in the diversity of life in marine waters. Examples of some of the significant recent advances, summarized by NRC (1995) include:

- The number of species
  - It is estimated that less than 10 per cent of marine species have been discovered. Consequently, measures of species richness and diversity may reflect the level of sampling effort in an area rather than true biological diversity.
  - Previous understanding of the ecology and evolution of deep-sea communities has been radically altered by the discovery that the diversity of deep-sea communities is much higher than previously thought.
  - Many undescribed species exist in 'familiar' environments, for example 158 species of polychaete worms were found in coral reef sediments from Hawaii, of which 112 species may be new.
  - New species and species assemblages have been discovered in novel habitats such as hydrothermal vents, whale carcasses and hydrocarbon seepage.
- Intraspecific genetic diversity
  - Seagrasses thought to be clonal have been found to possess high genetic diversity which has critical significance to community stability and management.
  - Recovery of threatened or endangered species whose abundance has been reduced to dangerously low levels may be at risk due to pronounced genetic 'bottlenecks' and reduced genetic variability, for example major inbreeding of humpback whales could have occurred if the international efforts to stop harvesting had not occurred when it did.
- Multispecies complexes
  - Cryptic sibling species have recently been discovered in important commercial species, including the oyster *Crassostrea*, the shrimp *Penaeus* and the stone crab *Menippe* with obvious implications for conservation and management. Similarly, the recent discovery that the US and Brazilian populations of Spanish mackerel were in fact two separate species that mature at different ages and sizes had dramatic implications for fisheries management.
- Novel groups
  - Immediately upon the introduction of new molecular techniques, previously unknown major bacterial groups were discovered in the sea. This, combined with the discovery of the widespread existence and abundance of marine viruses has fundamentally altered concepts of marine microbial diversity and the central role of microbes in global biogeochemical cycles.

Need for a systematic and integrated approach to marine conservation: Species, spaces, systems

The various present approaches to marine conservation – for example based on conservation of individual species, or habitats, or fisheries or ecosystem based management – are not at odds or in competition with one another. What we should seek is to integrate all the various approaches and initiatives within an overall ecologically logical framework. This is the fundamental attempt of this book.

Our basic question is: What should we aim to conserve? Our answer is: as many of the recognizable components of marine biodiversity as possible in networks of MPAs. Our problem then becomes: How do we decide WHAT we should conserve or preserve and how much of it (see Roff, 2009). Obviously, in the face of growing human use and exploitation of the marine environment, we cannot preserve everything; indeed we have already lost much.

However, there are certain principles that we can follow in order to develop coherent plans for marine conservation at global, national, regional and local levels, based on ecological concepts. With this as a foundation, individual groups, organizations and governments will be able to judge the importance, value and contributions of their conservation efforts and initiatives within a planning framework that spans the spatial hierarchy from global to local scales.

We believe that the important considerations for planning include the following:

Analysis of the spatial distribution of the components of biodiversity
Analysis of global biogeography
Understanding of relationships between habitats and communities
Conservation of Representative areas
Conservation of Distinctive areas
Analysis of the appropriate size of proposed MPAs
Proposal of candidate MPAs based on ecological principles
Definition of Coherent Sets of protected areas that encompass the above
Establishment of networks of MPAs
Attention to the coastal zone
Regulation of fisheries
Regulation of pollution

This list essentially defines the agenda for our book. Our presumption is that it is imperative to conserve as much as possible of the natural biodiversity of the oceans. In order to do this we need to recognize the components of marine biodiversity and how systematically to approach the complex business of marine conservation.

Some recurrent themes of the book

Certain themes will recur throughout this book. The first of these is the fundamental ecological hierarchy from genes to ecosystems – in fact, from genes to the biosphere as a whole. This hierarchy is just as natural to conservation ecologists as classification and taxonomy are to the biological systematist. Trying to preserve as many of the components of biodiversity as possible is a fundamental goal of marine conservation, even if many of the components at the ecosystem level are still beyond the present scope of human interference. The listings in Table 1.2 are not meant to be exhaustive or exclusive; but it presents a useful checklist against which to identify the important or irrelevant components of biodiversity at any spatial or temporal scale. Such a listing can therefore be useful to show how the components of biodiversity can be 'captured' in conservation planning. It can also be used to show at what level of the hierarchy or spatial scale conservation initiatives can be undertaken, from the local to the international scale.

Within the ecological hierarchy we can identify the structures and processes at each level (see Table 1.2). Structures are immediately recognized and measured (the number of organisms, the temperature of the water etc.), but processes present more problems. We generally infer processes from sequential measurements made at time intervals, or more likely simply from changes between separate observations. However, it is important to recognize the distinction between structures and processes because several different processes could in fact result in the same observed structures. Our explanations for the derivation of important structures may therefore be in error (a general cause for disagreement in science!) and consequent management decisions may be misinformed and misled.

The concept of scale has become important for all environmental and ecological enterprises, with the realization that a structure or process that is important at one scale may have little or no significance at another. For example, the process of diffusion is vital at a scale of millimetres to virtually all organisms (including respiration in humans!), but at larger scales it is overwhelmed by other processes of water motions. The important biological process of predation may be important in shaping population numbers and their distributions at local scales, but is generally replaced in significance at larger biogeographic scales by abiotic processes, or biotic processes of adaptations of individual species to their environment. The concept of scale, and judgement as to where and when a process may be of significance, is therefore always important in conservation planning. As we shall see, time and space scales tend to co-vary in the oceans, but relationships are often confused by the heterogeneity, variability and disturbances within natural systems.

The data we need to define 'natural regions' and their biota is often limited. Biological data at the required scale is sparse and temporally variable. Biological data is also expensive to collect and interpret. Recourse must therefore be had to spatially define both the ordinary (representative) and unique (distinctive) biological communities from geophysical surrogates. Physiographic and oceanographic variables, collected by a variety of means including remote sensing, can in fact quite well define biologically natural regions and their boundaries. With the growing realization that it is possible to draw lines on the oceans, this is a growing and vital area of research for marine conservation.

An overarching theme of this book will be the selection and establishment of MPAs based on sound ecological principles, and how these MPAs can be assembled into mutually supporting sets of protected areas. Ultimately this will culminate in showing how the goal – of networks of MPAs, promised by so many of the world's nations – can be achieved from global to local scales.

Conclusions and management implications

The oceans are of fundamental significance to the biological functioning of our planet. Life on earth without the 'goods and services' of the oceans is unthinkable. Biodiversity of life in the oceans runs the spectrum from the genetic to the ecosystem level. This ecological hierarchy allows us to appreciate the contribution of each level of organization to the structures and processes of marine life and their habitats.

The oceans are under threat from human activities and continue to degrade, causing loss of species and habitats. Measures to address these threats (legislation, education and awareness, international conventions, management tools etc.) are varied in their success.

Specific parts of the *Convention on Biological Diversity* refer to endangered species, threatened habitats and ecosystem management, including:

- Conserve biodiversity by establishing protected areas (Article 8).
- Recover endangered species and degraded ecosystems (Article 8).
- Protect traditional indigenous knowledge (Article 8).
- Integrate sustainable use principles into decision making (Article 10).
- Apply economic and social incentives for conservation (Article 11).

Marine conservation can be approached in a variety of ways but is fundamentally concerned with the preservation of marine biodiversity and the sustainable use of marine resources. Achieving a balance between preservation of biodiversity and resource utilization is the major challenge for marine conservation.

This book is primarily concerned with understanding the structure and function of marine environments in order to properly conserve and manage the world's oceans. There are many additional facets to marine conservation, including: law and policy; economic incentives; consumer education and awareness; property rights and so on, which are foundational to marine conservation efforts but not discussed in this volume.

This book is not primarily about marine management – only the ecological basis upon which management could be founded. Nevertheless, in each of the following chapters, we include a short section on conclusions and management implications of the ecological and environmental principles described. These sections should indicate how management could be achieved and at what spatial level or with what techniques.

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2

The Marine Environment: Physico-chemical Characteristics

Structures and processes – enduring and recurrent factors

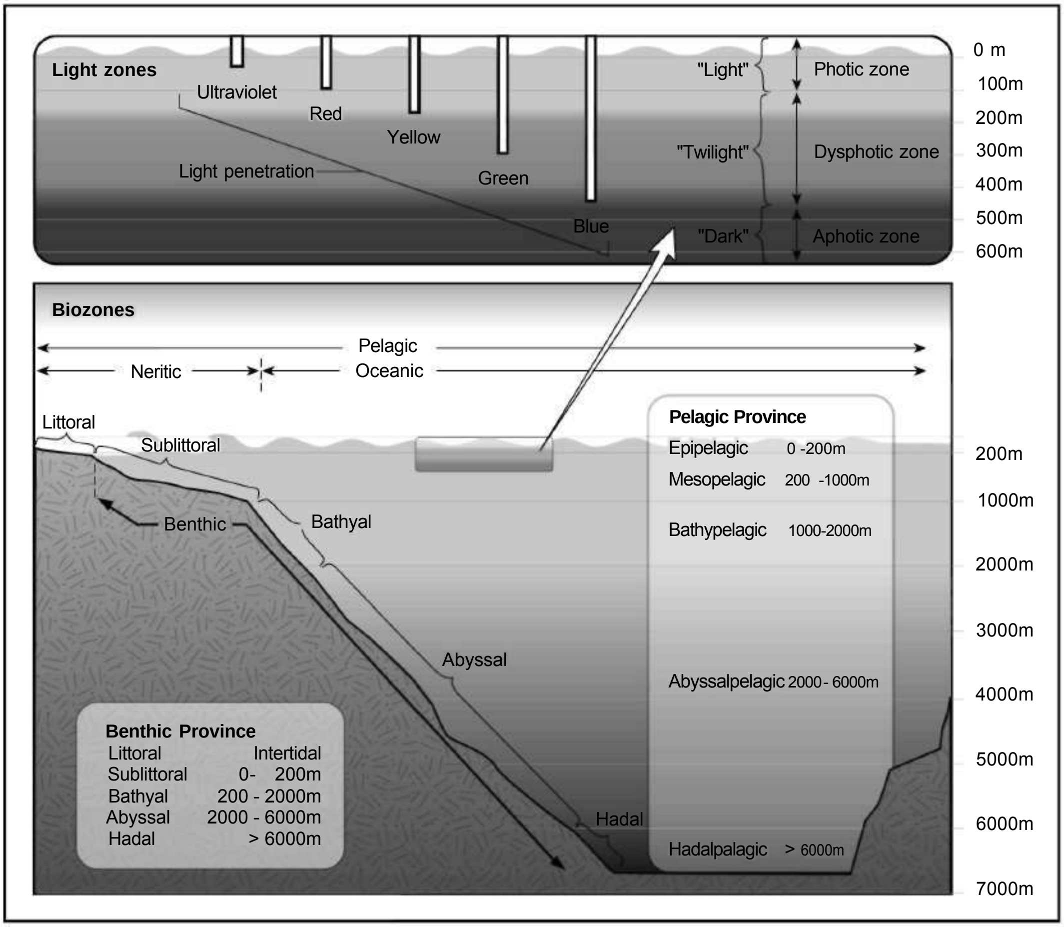
> *But more wonderful than the lore of old men and the lore of books is the secret lore of ocean.*
>
> H. P. Lovecraft (1890–1937)

Introduction

Marine conservation is a relatively new discipline, lagging behind terrestrial conservation (see e.g. Irish and Norse, 1996), but interest in it has been growing substantially in recent years. However, many practitioners who become engaged in marine conservation come to it from interests developed primarily in the terrestrial environment, perhaps unaware that the principles that apply to terrestrial habitats and conservation may or may not be transportable to the marine environment. In order to develop appropriate strategies and frameworks for marine conservation, we must acknowledge the inherent structures and processes of the marine environment. We should clearly note where they differ from those of terrestrial environments, and discern where terrestrial paradigms and approaches will not apply to marine systems.

For these reasons, this chapter presents a brief examination of the major physico-chemical characteristics of marine environments – which are the structure and process components of marine biodiversity at the habitat/ecosystem level of organization. The following Chapter 3 presents a brief review of some biological/ecological features of marine environments – which are the structure and process components of marine biodiversity at the species/population and community levels of organization. Consideration of the genetic level of organization is deferred until Chapter 10. An appreciation of how marine ecosystems are similar to and different from terrestrial ecosystems, and indeed from other aquatic ecosystems, is essential in order to 'set the scene' for the following chapters and concepts. These similarities and differences – for abiotic, and for biological/ecological characteristics – are summarized for marine and terrestrial ecosystems, for marine and other aquatic ecosystems and for arctic, sub-arctic, temperate sub-tropical and tropical ecosystems in Chapter 3.

A full description of the marine environment and its oceanography lies beyond the scope of



Source: Redrawn from various sources

Figure 2.1 Diagram of the pelagic and benthic realms of the marine environment, showing generally recognized vertical depth and light zones

this text. The emphasis here will be to introduce concepts, and factors (variables – which can be measured directly; and parameters – composites of variables) both enduring and recurrent, that are involved in shaping the character of marine communities, relevant to the distribution of the components of marine biodiversity, and that will inform decisions for marine conservation planning. Enduring factors are those that persist at a given location over time (e.g. substrate type), and recurrent factors are those that periodically change in predictable ways (e.g. tides and currents). We shall consider these factors as belonging to two main types: structures and processes; and as belonging to two main categories: physiographic – pertaining to the ocean basin itself, and oceanographic – pertaining to the water column.

A fundamental division of the oceans, that affects all further considerations, is into two major realms: the *pelagic* and *benthic* realms (Figure 2.1). The pelagic realm is the water column itself and all the organisms that inhabit it. The benthic realm is the sea-floor with all the creatures that live within or upon it. The pelagic realm is a fully three-dimensional world while in comparison, to a first approximation, the benthic realm

Box 2.1 Selected recommended reading as background to the physics, chemistry and biology of the oceans

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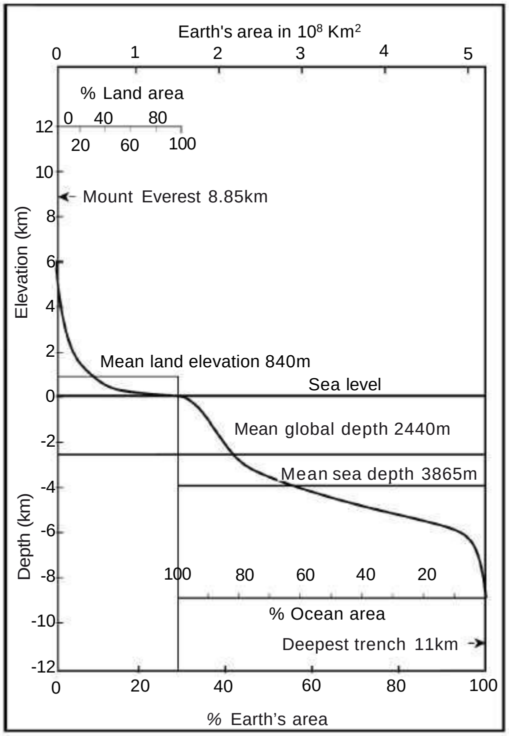
can be considered as nearly two dimensional. The two realms are intimately and continuously connected by a variety of physico-chemical and biological processes, but if we analyse these two realms separately (as it is often convenient and simpler to do), then we must consider the oceans as effectively comprising no less than five dimensions! Oceanographic factors apply primarily to the pelagic realm, with physiographic structures only becoming of significance where submarine topography affects oceanographic processes. Physiographic factors primarily apply to the benthic realm, but oceanographic structures and processes are also significant. Such classifications are very important for conservation planning, even though our human bias is naturally towards the familiar shoreline.

For a fuller consideration of the fundamentals of oceanography and marine biology/ecology, the reader is referred to – among others – the texts listed in Box 2.1.

Major features of the oceans – physiographic structures

Physiographic characteristics are those features broadly recognized as 'marine landform' – in essence relating to the topography and substrates of the sea-floor. The physiography of the shoreline and seabed determines the broad character of benthic biological communities, though there are overlying geological, biogeographical and oceanographic contexts, which are responsible



Source: Redrawn from various sources

Figure 2.2 Hypsographic curve of the terrestrial and marine environments, showing the distribution of elevations and depths on earth

for large-scale differences in biological communities. The physiography of coastlines and the sea-bottom is one of the easiest components to map, and with satellite, airborne and in situ sensing technologies, considerable accuracy is available or possible.

Area, depth and volume

Collectively, the oceans of the world cover 70.6 per cent of the surface of the globe. The average depth of the oceans is approximately 3.8km and maximum depths exceed 10km. The volume of all the oceans and seas combined is an immense 1370 x 10^6km^3. A hypsographic curve of lands and seas (Figure 2.2) clearly shows the preponderance of living volume in the oceans over that on land. Life on land (29.3 per cent of the area of the globe) extends from only a few metres below ground – in caves, plant roots and in geological fractures – to a few metres above ground – at the tops of trees (discounting birds, which are still land referenced). In contrast, life in the oceans extends from surface waters to over 10,000m in depth. Therefore well over 99 per cent of the habitable volume for the biota of our planet is in the oceans.

Horizontal divisions and bathymetry

In the horizontal dimension, the marine environment is generally regarded as divisible into several major provinces (Figure 2.1). Coastal waters comprising the *coastal zone* (variously defined – see Chapter 11 – but here regarded as less than 30m in depth) extend seaward from the high water level and include the *littoral zone*. Near to shore are various kinds of *inlets* including estuaries, bays and coves and associated wetlands. *Estuaries* are the meeting place of freshwaters with the ocean, where the salinity is measurably diluted by freshwater runoff (see below). *Bays* and *coves* are shoreline concavities of the ocean where salinity may not be diluted (unless they are bays *within* estuaries). The coastal regions run into the *neritic province* of *sub-littoral waters*, which is the region of the ocean that lies above the *continental shelf* out to depths of 200m. Although the edge of the continental shelf corresponds to the *exclusive economic zones* (EEZ) of nations in some places, in most places around the world there is no relationship between the two. Some implications of this will become clear in Chapter 12 on Deep Seas and High Seas. The neritic province then merges into the *oceanic province* at the *shelf edge* or the *shelf break*. The oceanic province comprises those vast areas of the oceans that physically lie beyond the edge of the continental shelves and whose waters exceed depths greater than 200m.

Depth, light and pressure

The next major division of the oceans is made in terms of depth, where a variety of terms is used to describe the habitats and their biological communities. The conventional descriptive divisions of the oceans with respect to depth, which have long been recognized, are shown for both the pelagic and benthic realms in Figure 2.1. Depth is an important factor in both the pelagic and benthic realms. In combination with temperature, salinity, light and pressure (with which it co-varies) it defines the distributions of major community types (e.g. Glenmarec, 1973).

Somewhat arbitrarily, the oceans are vertically subdivided into the *epipelagic* (down to 200m), the *mesopelagic* (200 to 1000m), and the *bathypelagic* zones (1000 to 2000m) and *abyssal/hadal* zones (>2000m). Similar terms are applied to the benthic realm (see Figure 2.1).

Light intensity diminishes exponentially with depth in the oceans. In the vertical dimension, and very fundamentally as far as the photosynthetic organisms are concerned, the oceans can therefore be subdivided as follows: the *euphotic* (= photic, or well lighted) zone is the region in which sufficient light penetrates to allow net photosynthesis and plant growth to occur; below this is the *dysphotic* (or poorly lighted) zone where light is still present, but its intensity is too low to support plant growth; below this again, the great majority of the oceans' depths lie within the *aphotic* zone, where no light penetrates (Figure 2.1).

Light provides the energy for photosynthesis and primary production in most marine ecosystems. The penetration of light within the water column is attenuated with both depth and turbidity, and both parameters are important determinants of the vertical distribution of pelagic and benthic vegetation. The euphotic, dysphotic and aphotic zones are real, functional zones which limit the development and types of biological communities. The division between the photic and non-photic zones is more significant than the further subdivisions (dysphotic and aphotic) within it. Beyond the limits of the euphotic zone lie the dysphotic and aphotic regions, defining communities which cannot photosynthesize. At these depths, energy for consumers is imported from other areas, predominantly by vertical settling of detritus from upper layers of the sea. Consequently the whole trophic structure of communities below the euphotic zone is different from those within it, and is dependent upon detrital carbon. With increasing depth, the amount of available food declines exponentially as a function of surface productivity (e.g. Suess, 1980).

The compensation point occurs at the bottom of the euphotic zone, a depth below which the rate of respiration exceeds the rate of photosynthesis. The actual depth of the euphotic zone increases with water depth itself, from the coast towards the edge of the shelf and into oceanic waters, and it also varies at different times of the year. For example, in estuaries, the euphotic zone may be less than 2m in depth, in average coastal waters it approximates 30–50m, while in oceanic waters it may exceed 200m. Similarly in the Arctic Ocean, the euphotic zone may exceed 100m during the spring, and suddenly decrease to only a few metres during the summer phytoplankton bloom. The biomass and productivity of phytoplankton can be estimated from ocean colour and water clarity (e.g. Bukata et al, 1995). Light penetration and turbidity are also important determinants of submergent vegetation.

Depth is also a surrogate variable for *pressure*. The increase in pressure with depth has a significant impact on organisms. With every ten metres of depth, the water pressure increases by approximately one atmosphere (with the greatest change from 0 to 1 atmosphere occurring in the top ten metres). Additional physical, chemical and biological changes lead to a decrease of dissolved oxygen and increase of dissolved carbon dioxide (see below). Organisms which live in the deeper regions of the oceans are adapted to these physical conditions of high pressure, low temperatures and dilute resource concentrations, and rarely move into the epipelagic region.

Temperature also decreases with depth, from ambient surface values to a nearly constant 0–4°C in deepest oceanic waters. Conversely, salinity typically increases with depth. Concentrations of particulate organic carbon (the detrital flux from the euphotic zone) also decrease exponentially with depth, while oxygen concentrations decline and carbon dioxide concentrations increase with depth. Depth is therefore an index of a variety of concurrently changing physical and chemical conditions, which collectively influence the nature of biological communities.

Basin morphometry and topography

The general topography or morphometry of a region (e.g. an estuary, inlet, basin) can exert a significant effect on the character of a coastal region. For example, at a large scale, an entire basin may have a natural period of oscillation that reinforces the local tidal frequency. In such a case, resonance occurs, and very high tides and rapid tidal currents are observed. A prime example of this in Canadian waters is the Bay of Fundy, Nova Scotia. In such conditions, the high tidal range and fast currents may determine that the local substrate consists of coarse particles or even bare rock for considerable distances. At the opposite extreme, where a local basin experiences low tides, sedimentary areas usually predominate. However, because the tidal amplitude and nature of the substrate can be independently obtained, and because substrate type is also a function of geology and wave action, these factors may be assessed directly, rather than interpreted from morphometric characters.

At finer scales, topography can have profound effects on marine fauna and flora. A particular marine phenomenon, which is unlikely to be captured in any regional study of the distribution of marine geophysical features, is the existence of underwater marine caves. Localized 'pockets' of organisms either not found elsewhere, or only sparsely existing in other locations, may thrive in marine caves. These are the kinds of habitats beloved of SCUBA divers, and essentially inaccessible by other means. Sampling from the surface generally does not reveal their existence. These constitute 'distinctive' faunas, exhibiting the phenomena of 'interiority' (Morton et al, 1991) and spatial heterogeneity (Bergeron and Bourget, 1986) at the smallest scales.

Relief and slope

Relief applies to the vertical change in height in relation to horizontal distance, and provides an indication of slope. The shoreline slope, in combination with local tidal amplitude, determines the extent of the intertidal zone. Slope and exposure also influence the substrate type in intertidal regions. Steep slopes and high exposure lead to bare rock, while intertidal mud-flats occur at the opposite end of the slope and energy spectrum.

The relief (also variously described as slope, rate of change of slope, rugosity or benthic complexity) at the shoreline and within coastal and marine waters is highly variable. While slope intervals are sometimes mapped, slope is more often inferred from vertical changes in height in relation to horizontal distance (i.e. steeper slope where bathymetric contours are closer together). Depth and hence slope is generally mapped in more detail in areas of navigable waters. However, it is important to remember that a calculated slope depends on the frequency of data points.

Areas of high relief tend to have irregular bottom morphologies and high elevation ranges; low relief areas have uniform slopes with small elevation gradients. High relief areas provide habitat for numerous species assemblages and may indicate high species richness, diversity and biomass (Lamb and Edgell, 1986). Relief may also be an indirect indication of mixing. Sediment stability is partly dependent upon slope, while the angle of repose of marine sediments depends on particle size and activity of water motion. Stable marine slopes for sediment accumulation are much lower than for terrestrial slopes of similar grain sizes.

Relief and slope characteristics are generally considered as secondary diagnostics, compared to direct knowledge of substrate type, current speed, exposure and so on. These factors may, however, become useful as predictors of local substrate type under some circumstances, where direct data on substrate type is not available (e.g. regions of the Arctic), but in most cases where substrate type and current velocities are known, these factors may add little extra information concerning biological community types. An exception to this may be at the edge of the continental shelf, where the change in substrate slope itself, in concert with current activity, may enhance local benthic production by processes not yet well understood.

Substrate type and particle size

Substrate particle size is a dominant influence on marine communities. It is frequently classified