Manual of marine and coastal datasets of biodiversity importance.

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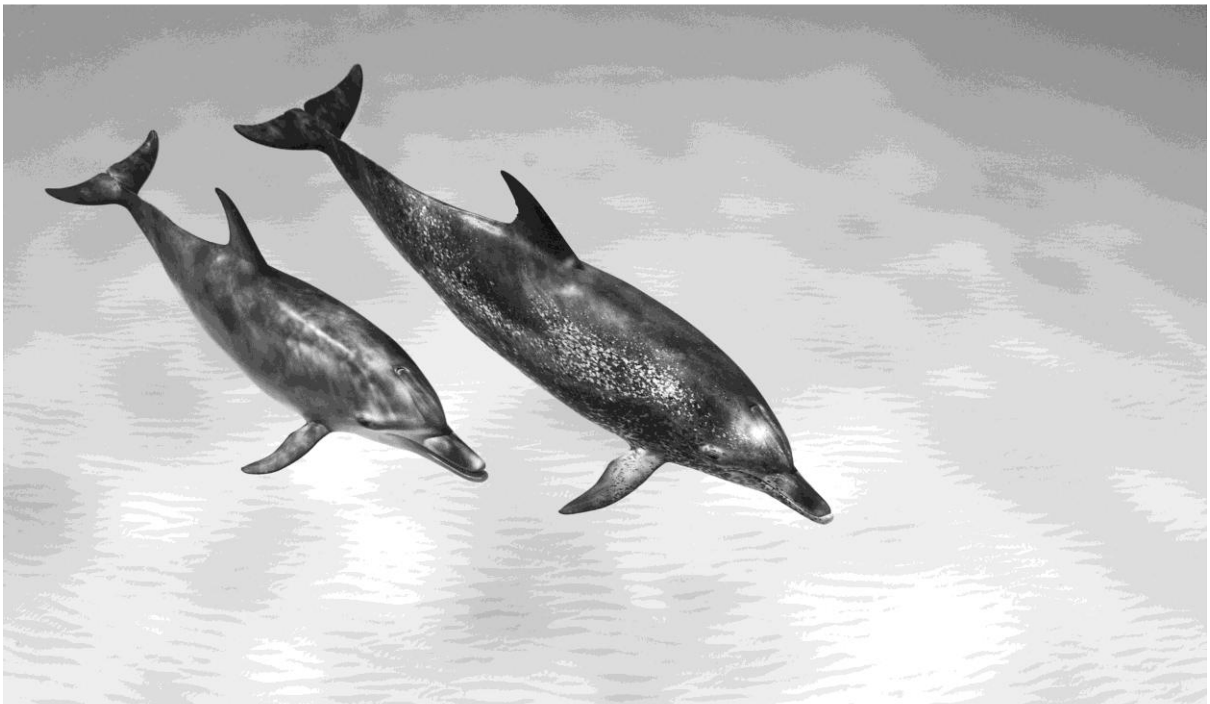

An introduction to key marine and coastal biodiversity datasets

UNEP

Manual of marine and coastal datasets of biodiversity importance

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The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) is the specialist biodiversity assessment centre of the United Nations Environment Programme (UNEP), the world's foremost intergovernmental environmental organisation. The Centre has been in operation for over 30 years, combining scientific research with practical policy advice.

Cover page image: pair of Atlantic spotted dolphins (*Stenella frontalisllis*), Copyright: A. Cotton, 2014 (Image ID: 107332184). Used under license from Shutterstock.com.

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Executive summary

English. Knowledge of marine and coastal datasets tends to be fragmented and/or difficult to access for the non-expert or ad hoc data user. To address this lack of information, this document provides an overview of global marine and coastal datasets of biodiversity importance, and also includes some datasets of regional interest. This non-exhaustive review has resulted in the identification of 78 datasets and/or databases and data portals. Detailed standardised metadata are presented for 45 of these reviewed datasets. The various challenges, gaps and limitation which can be presented by coastal and marine data are also discussed. A set of four annexes provides a wealth of information including background factsheets on topic areas (annex 1), a preliminary inventory of 78 global and regional datasets (annex 2) and dataset-specific metadata on 45 of these (annex 3). Annex 4 contains a sample of 10 marine mammal spatial distribution maps, as modelled using the AquaMaps approach.

Français. La connaissance des données marines et côtières est généralement fragmentée et/ou difficile d'accès pour le non-expert ou l'utilisateur ad hoc. Pour remédier à ce manque d'information, ce document donne un aperçu des données marines et côtières d'importance pour la biodiversité, à l'échelle mondiale, et inclut également des données d'intérêt régional. Cet inventaire non exhaustif a permis d'identifier 78 ensembles et/ou portails de données. Des métadonnées détaillées et standardisées sont présentées pour 45 d'entre eux. Les défis, lacunes et limites qui peuvent être présentés par les données marines et côtières sont également discutés. Quatre annexes fournissent de nombreux renseignements : des fiches thématiques (annexe 1), un inventaire préliminaire de 78 ensembles et/ou portails de données aux échelles mondiales et régionales (annexe 2), et des métadonnées pour 45 d'entre eux (annexe 3). L'annexe 4 présente un échantillon de cartes de distribution pour 10 mammifères marins, basées sur l'approche de modélisation AquaMaps.

Español. El conocimiento acerca de los conjuntos de datos marinos y costeros tiende a ser incompleto y/o no siempre está al alcance de las personas no expertas o los usuarios ad hoc. Para remediar estas carencias referentes a la información, este documento pretende ofrecer un sumario que agrupe todos los datos marinos y costeros de importancia para la biodiversidad a nivel mundial, e incluye además conjuntos de datos de interés regional. Este inventario no exhaustivo ha permitido identificar 78 conjuntos y/o portales de datos. Para 45 de estos 78 conjuntos se presentan metadatos detallados y estandarizados. Los desafíos, lagunas y limitaciones que podrían surgir a partir de estos datos son igualmente discutidos. Cuatro anexos proporcionan numerosas reseñas: fichas temáticas (anexo 1), un inventario preliminar con 78 conjuntos de datos a escala mundial y regional (anexo 2), y metadatos para al menos 45 de ellos (anexo 3). El anexo 4 contiene una muestra de mapas de distribución para 10 mamíferos marinos, todos ellos basados en una modelización obtenida a través de AquaMaps.

1. Introduction

Knowledge of marine and coastal datasets tends to be fragmented and/or difficult to access for the non-expert or *ad hoc* data user. Data users may have difficulties in assessing the suitability of a particular dataset for their specific needs, and in accessing the information necessary for optimal use of these data. These issues can be compounded by a lack of information on the biodiversity features for which there are datasets available. To address the lack of information, this document provides an overview of global marine and coastal datasets of biodiversity importance and also includes some datasets of regional interest.

In this document, *datasets of biodiversity importance* are defined as those datasets that can be used to identify geographic areas which contain significant biodiversity, in the broadest sense of the term. We define as *marine* a dataset covering a section of the sea, without any terrestrial component (e.g. coral, seagrass bed), whilst a *coastal dataset* would have both a marine and a terrestrial component (e.g. mangrove, saltmarsh).

In addition to the information provided on the datasets which exist, the various challenges, gaps and limitation which can be presented by coastal and marine data are also discussed (section 4); these include spatial and temporal gaps and bias, data types (e.g. point, polygon), modelled versus observed data, and spatial and temporal scales. The ways in which the scientific community tries to address these availability and quality issues are also highlighted. Such issues also exist in the terrestrial realm, but they tend to be significantly more acute in the marine realm: data users are confronted with significant and specific difficulties in the identification and use of coastal and marine datasets.

The document is structured as follows:

- *section 2* gives some background to the work and discusses the scope of the review;
- *section 3* provides information on the different datasets reviewed and highlights how these have been grouped into nine categories;
- *section 4* discusses the issues around data and highlights the gaps which can occur, along with some additional information on data use; and
- a set of four annexes provides a wealth of information including *background factsheets* on topic areas (*annex 1*), a preliminary inventory of global datasets (*annex 2*), and dataset-specific metadata on a subset of these (*annex 3*). *Annex 4* contains a sample of marine mammal spatial distribution maps, as modelled using the AquaMaps approach.

It is hoped these documents will aid the understanding of the different datasets which have been produced by various organisations around the world.

2. Aim and scope

The starting point for this work was an identified need to better document and explain the various marine and coastal datasets currently curated and/or distributed by the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), including what the datasets show, why they were created, how they can be used, their limitations and access details (such as the data owner details, use restrictions, web map service links[1]). To date, a total of 22 marine and coastal datasets can be viewed and/or downloaded from UNEP-WCMC's *Ocean Data Viewer*[2] (ODV) and related *Data Download*[3] page. This documentation work resulted in the development of standardised 'metadata'[4] sheets for each of these 22 datasets, but also for other datasets internally curated by UNEP-WCMC, and which are not on these online data portals.

The scope of the work included an initial review of marine and coastal datasets of biodiversity importance created and curated by other organisations or scientific initiatives. This non-exhaustive review resulted in the identification of 78[5] datasets and/or databases and data portals, and including the UNEP-WCMC datasets mentioned above. Datasets were grouped into nine broad categories listed in Table 1. To date, UNEP-WCMC has produced detailed standardised metadata[6] for 45 of these reviewed datasets. These metadata were written in the same standardised format as the information produced for the UNEP-WCMC curated datasets, to provide a comparable source of information for the variety of data which have been created for the marine environment. Creating a standardised metadata was done to bring together, as far as possible, all relevant information on the individual datasets into one place, for ease of access and comparison. It is anticipated that, as far as is practical, all datasets will eventually have detailed metadata written, to further continue our aim to help the understanding of marine data.

In addition to the dataset-specific metadata, complementary 'background factsheets', often relevant to several datasets, were developed so as to provide general information on a biodiversity feature (e.g. ecology, creation methodology, etc), and explanations of its biodiversity importance including, where relevant, policy and governance aspects. A list of these background factsheets written or under development is provided in Table 1.

[1] These can be used in web mapping applications such as ArcGIS.com, SeaSketch, etc.
[2] http://data.unep-wcmc.org (20 datasets for viewing, of which 15 can be downloaded). Note that protected area data is downloadable from Protected Planet (http://www.protectedplanet.net/), not from the ODV. For commercial use of these datasets, please contact business-support@unep-wcmc.org.
[3] http://datadownload.unep-wcmc.org/datasets (2 datasets for download). For commercial use of these datasets, please contact business-support@unep-wcmc.org.
[4] Metadata are "data about data".
[5] See Annex 2 for a summary table listing all the datasets reviewed.
[6] See Annex 3 for a compilation of metadata sheets available to date. Metadata were written in priority for datasets curated/distributed by UNEP-WCMC, and for datasets likely to be of interest to UNEP-WCMC within the framework of its projects.

Table 1. The nine broad categories used to classify the 78 datasets, and their background factsheets. Those factsheets in square brackets are under development (*: anticipated to be available for the next update of this document). Factsheets are compiled in annex 1. SDM: Species Distribution Modelling (see section 4).

Category	Factsheet name	Page
Biogenic habitat	Warm-water coral reef	p. 30
	Cold-water coral	p. 33
	[Coralligenous and maerl (Mediterranean)]	*
	Mangrove	p. 35
	Seagrass	p. 39
	Saltmarsh	p. 41
Species habitat	Marine turtle (nesting site)	p. 43
	[Marine turtle (feeding site)]	
Species distribution	[Occurrence, range, and SDM]	
Biodiversity metric	[Biodiversity metric]	*
Area of biodiversity importance	[Protected area (marine subset)]	
	[Key Biodiversity Areas (marine subset)]	
	[Ecologically or Biologically Sensitive Area]	*
	Vulnerable Marine Ecosystem	p. 55
	[Particularly Sensitive Sea Area]	
	[Area of Particular Environmental Interest]	
	[Critical Habitat (IFC PS6's definition)]	
Biogeographic classification	[Biogeographic classification]	*
	[Global 200 ecoregions (marine subset)]	
	Seamount	p. 46
	Hydrothermal vent	p. 49
	Cold seep	p. 51
Ecological status and impact	[Ecological status and impact]	
Environment descriptor	[Environment descriptor]	*
Administration	Not applicable	

This document is by no means an exhaustive inventory of all existing datasets of biodiversity importance. Rather, it aims to act as a manual for marine and coastal datasets of biodiversity importance. It should be considered a *living* document, which will be continuously updated as more datasets come to light and feedback is received. In this regard, we welcome comments from data curators, owners, users and experts, so that this document can be maintained as accurate, updated and useful as possible. Further factsheets are also planned and will be included in future updates of this document. It is hoped that this document will facilitate access to, understanding of, and optimal use of marine and coastal datasets of biodiversity importance.

3. Key marine and coastal biodiversity datasets

Nine broad categories (see Table 1 in section 2) were used to classify the 78 marine and coastal datasets we identified. In this section, the identified datasets are listed by category; the availability of metadata in annex 3 is indicated (✓), and also the name of the corresponding background factsheet in annex 1[7]. Datasets that are currently directly **downloadable** from UNEP-WCMC's *Ocean Data Viewer* and related *Data Download* page are indicated using this coloured shading.

Biogenic habitat

'Biogenic' habitats are those habitats created by plants or animals, and that grow in such manner that they provide a unique environment and physical structure for other organisms to live (Tyrrell 2005). Examples of marine and coastal biogenic habitats include (warm- and cold-water) corals, mangroves, saltmarshes, seagrass meadows and kelp beds.

Table 2. Global (and regional) datasets in the 'biogenic habitat' category. Associated factsheet names are given (the one in square brackets is under development. Coloured shading indicates that the datasets are directly downloadable from the *Ocean Data Viewer*.

Dataset title	ID[8]	Metadata	Factsheet name
Global Distribution of Coral Reefs (2010)	WCMC-008	✓	Warm-water coral reef
Global Distribution of Coral Reefs - 1 Km Data (2003)	WCMC-009	✓	Warm-water coral reef
Global Distribution of Cold-water Corals (2005)	WCMC-001	✓	Cold-water coral
Global Distributions of Habitat Suitability for Framework-Forming Cold-Water Corals (2011)	Bangor-001		Cold-water coral
Global Distribution of Habitat Suitability for Stony Corals on Seamounts (2009)	WCMC-024		Cold-water coral
Global Distributions of Habitat Suitability for Cold-Water Octocorals (2012)	ZSL-001	✓	Cold-water coral
Modelled Mediterranean Coralligenous and Mäerl Distributions (2013)	Mediseh-001	✓	[Coralligenous and maerl (Mediterranean)]
Global Distribution of Mangroves USGS (2011)	WCMC-010	✓	Mangrove
World Atlas of Mangroves (2010)	WCMC-011	✓	Mangrove
Global Distribution of Mangroves (1997)	WCMC-012	✓	Mangrove
Global Distribution of Seagrasses (2005)	WCMC-013-014	✓	Seagrass
Modelled *Posidonia oceanica* Distribution in the Mediterranean Sea (2013)	Mediseh-002	✓	Seagrass
Global Distribution of Saltmarsh (2013)	WCMC-027	✓	Saltmarsh

In this review, we identified 13 datasets (Table 2) showing the global or regional distributions of biogenic habitats, of which 11 have detailed metadata. Two warm-water coral reef and three mangrove datasets can be downloadable from the *Ocean Data Viewer*. Please refer to the detailed

[7] See Table 1 for page numbers to access them in this document.
[8] Internal UNEP-WCMC numbering system as part of our metadata cataloguing.

metadata to access information on the differences between these datasets and to select the most appropriate dataset for a particular use.

Species habitat

The Convention on Biological Diversity (CBD; 1992) defines habitat as the place or type of site where an organism or population naturally occurs. In this document, the term habitat is understood in the sense of 'biotope', which comprises the abiotic[9] characteristics of a site and the associated biological community. In simple terms, a habitat is where an animal or plant species lives (including migratory routes), feeds (e.g. foraging sites) and reproduces (e.g. breeding, spawning, nesting, and nursery sites). The habitat of a species may hence change throughout its life cycle: fish eggs and larvae for instance are found in very different habitats to juvenile and adult fish. Similarly, female marine turtles lay eggs on nesting beaches but spend the rest of their lives (e.g. foraging, migrating) at sea.

In this review, we identified four datasets (Table 3) showing the global distribution of species habitats, of which two have detailed metadata. At present, all four datasets are for marine turtles.

Table 3. Global datasets in the 'species habitat' category. Associated factsheet names are given (the one in square brackets is under development). Coloured shading indicates that the datasets are directly downloadable from the *Data Download* page.

Dataset title	**ID**	**Metadata**	**Factsheet name**
Global Distribution of Marine Turtle Nesting Sites (1999)	WCMC-007	✓	Marine turtle (nesting site)
Global Distribution of Marine Turtle Nesting Sites (2011)	SWOT-001		Marine turtle (nesting site)
Global Distributions of Habitat Suitability for Marine Turtle Nesting Sites (2012)	SWOT-002		Marine turtle (nesting site)
Global Distribution of Marine Turtle Feeding Sites (1999)	WCMC-006	✓	[Marine turtle (feeding site)]

Species distribution

The distribution of a species is understood here as the geographical spaces where the species may be found. Species distributions can be expert-derived or predicted by numerical models, the latter often informing on the relative probability of occurrence at given locations.

In this review, we identified 18 datasets (Table 4) showing the global or regional distributions of species, of which 10 have detailed metadata. These 10 datasets come from the same source (AquaMaps), and methodological information is available in annex 4.

[9] i.e. non-living, applied to the physical and chemical aspects of an organism's environment (http://terms.biodiversitya-z.org/terms/5).

Table 4. Global (and regional) datasets in the 'species distribution' category. The factsheet which applies to all datasets in this section is under development. SDM: Species Distribution Modelling (see section 4).

Dataset title	ID	Metadata	Factsheet name
Spatial Data for the Red List of Threatened Species (2013)	IUCN-001		[Occurrence, range, and SDM]
Global Register of Migratory Species (2004)	GROMS-001		[Occurrence, range, and SDM]
Global Distribution of Marine Turtles (2010)	SWOT-003		[Occurrence, range, and SDM]
AquaMaps: Predicted Range Maps for Aquatic Species (2013)	AquaMaps-001		[Occurrence, range, and SDM]
Global Distribution of Northern Fur Seals (2013)	Kaschner-001	✓	[Occurrence, range, and SDM]
Global Distribution of Hawaiian Monk Seals (2013)	Kaschner-002	✓	[Occurrence, range, and SDM]
Global Distribution of Grey Seals (2013)	Kaschner-003	✓	[Occurrence, range, and SDM]
Global Distribution of Hector's Dolphins (2013)	Kaschner-004	✓	[Occurrence, range, and SDM]
Global Distribution of Northern Bottlenose Whales (2013)	Kaschner-005	✓	[Occurrence, range, and SDM]
Global Distribution of Sperm Whales (2013)	Kaschner-006	✓	[Occurrence, range, and SDM]
Global Distribution of Bowhead Whales (2013)	Kaschner-008	✓	[Occurrence, range, and SDM]
Global Distribution of Sei Whales (2013)	Kaschner-009	✓	[Occurrence, range, and SDM]
Global Distribution of Atlantic Spotted Dolphins (2013)	Kaschner-011	✓	[Occurrence, range, and SDM]
Global Distribution of Melon-Headed Whales (2013)	Kaschner-012	✓	[Occurrence, range, and SDM]
Marine Species Datasets of the World's Oceans (2014)	OBIS-003		[Occurrence, range, and SDM]
Global Shark Distribution Database (2009)	UniDalh-002		[Occurrence, range, and SDM]
Marine Animal Tracking (2013)	UniDalh-001		[Occurrence, range, and SDM]
Tagging of Pacific Predators in the Pacific Ocean (2013)	TOPP-001		[Occurrence, range, and SDM]

Biodiversity metric

Biodiversity metrics are designed to numerically measure the value of biodiversity in space and time. They can, for instance, be used to monitor biodiversity changes through time, or to identify areas of high biodiversity value such as sites showing high levels of species richness.

In this review, we identified five datasets (Table 5) showing the global distribution of biodiversity metrics, of which four have detailed metadata.

Table 5. Global datasets in the 'biodiversity metric' category. The factsheet which applies to all datasets in this section is under development. Coloured shading indicate that the datasets are directly downloadable from the *Ocean Data Viewer*.

Dataset title	ID	Metadata	Factsheet name
Global Patterns of Marine Biodiversity (2010)*	WCMC-019	✓	[Biodiversity metric]
Global Map of Shannon's Index of Biodiversity (2014)	OBIS-001	✓	[Biodiversity metric]
Global Map of Hurlbert's Index of Biodiversity (2014)	OBIS-002	✓	[Biodiversity metric]
Global Seagrass Species Richness (2003)	WCMC-015	✓	[Biodiversity metric]
Global Marine Turtle Species Richness (2002)	WCMC-003		[Biodiversity metric]
Species Richness Maps (2013)	AquaMaps-002		[Biodiversity metric]

* (Tittensor, Mora, et al. 2010)

Area of biodiversity importance

Areas of biodiversity importance include a range of nationally and internationally protected areas (e.g. World Heritage Sites, the Natura 2000 network), as well as the many approaches used to highlight areas of biodiversity conservation interest (e.g. Key Biodiversity Areas, Ecologically or Biologically Significant Areas, Critical Habitat).

In this review, we identified seven datasets (Table 6) showing the global distribution of areas of biodiversity importance, of which three have detailed metadata.

Table 6. Global (and regional) datasets in the 'Area of biodiversity importance' category. Associated factsheet names are given (those in square brackets are under development).

Dataset title	ID	Metadata	Factsheet name
World Database on Protected Areas (2013)	WCMC-016	✓	[Protected area (marine subset)]
Global Distribution of KBAs, IBAs and AZEs (2013)	Birdlife-001	✓	[Key Biodiversity Areas (marine subset)]
Ecologically or Biologically Significant Areas in the Mediterranean Sea (2010)	RAC-SPA-001	✓	[Ecologically or Biologically Sensitive Area]
Global Distribution of Vulnerable Marine Ecosystems (*expected* 2014)	FAO-002		Vulnerable Marine Ecosystem
Global Distribution of Particularly Sensitive Sea Areas (2012)	IMO-001		[Particularly Sensitive Sea Area]
Areas of Particular Environmental Interest (2012)	ISA-001		[Area of Particular Environmental Interest]
A Global Map of Critical Habitat (2013) as per IFC PS6	WCMC-029		[Critical Habitat (IFC PS6's definition)]

Biogeographic classification

Biogeographic classifications are used to understand how and where species are distributed, and to mark the boundaries between oceanographic regimes. They help assessing which habitats, communities and species could be subject to disproportionate impact, because of concentration of human activities, rarity, or limited extent of distribution.

In this review, we identified 13 datasets (Table 7) showing global biogeographic classifications (partial or complete), of which six have detailed metadata.

Table 7. Global datasets in the 'biogeographic classification' category. Associated factsheet names are given (those in square brackets are under development). Coloured shading indicate that the datasets are directly downloadable from the *Ocean Data Viewer*.

Dataset title	ID	Metadata	Factsheet name
Marine Ecoregions of the World (2007)	WCMC-017	✓	[Biogeographic classification]
Pelagic Provinces of the World (2012)	WCMC-018	✓	[Biogeographic classification]
A Proposed Biogeography of the Deep Oceans (2013)	UniHaw-001		[Biogeographic classification]
Large Marine Ecosystems of the World (2002)	NOAA-001		[Biogeographic classification]
Longhurst Biogeographical Provinces (2006)	VLIZ-002		[Biogeographic classification]
The Global 200 Ecoregions (2002)	WWF-001		[Global 200 ecoregions (marine subset)]
Geomorphology of the oceans (2014)	BlueHab-001		[Biogeographic classification]
Global Distribution of Seamounts and Knolls (2011)	ZSL-002	✓	Seamount
Global Seamount Database (2011)	UniHaw-003		Seamount
SeamountsOnline: an Online Information System for Seamount Biology (2009)	UniCal-001		Seamount
Global Distribution of Hydrothermal Vents (2010)	ChEssBase-002	✓	Hydrothermal vent
Global Distribution of Hydrothermal Vent Fields (2013)	IntRid-001	✓	Hydrothermal vent
Global Distribution of Cold Seeps (2010)	ChEssBase-001	✓	Cold seep

Ecological status and impact

Ecological status describes the degree to which human uses of the environment have altered the structure and functioning of plant and animal communities. A geographical area can be assigned an ecological status class (e.g. high, good, moderate, poor, or bad) depending on the degree of alteration to the environment in that location. For instance, a *high* ecological status corresponds to areas relatively undisturbed by man, and *good* ecological status to areas where human activities have had only slight impacts on the ecological characteristics of plants and animal communities there. Impact is here understood in the broadest sense of the term, i.e. from disease affecting ecosystems to human impact through diving.

In this review, we identified five datasets (Table 8) showing the global distribution of ecological status and impact, two of which have detailed metadata.

Table 8. Global datasets in the 'Ecological status and impact' category. The factsheet which applies to all datasets in this section is under development.

Dataset title	ID	Metadata	Factsheet name
A Global Map of Human Impacts to Marine Ecosystems (2008)	NCEAS-001		[Ecological status and impact]
Global Data for the Ocean Health Index (2012)	NCEAS-002		[Ecological status and impact]
SeagrassNet: Global Seagrass Monitoring Network (2013)	WaDNR-001	✓	[Ecological status and impact]
Coral Disease Database (2009)	WCMC-004		[Ecological status and impact]
Global Distribution of Dive Centres (2001)	WCMC-030		[Ecological status and impact]

Environment descriptor

Environment descriptors are defined here as variables that can be used to depict the environment. They include physical (e.g. bathymetry, seabed sediment type) and environmental (temperature, salinity) variables, but also biological ones such as productivity. Environment descriptors can be used to monitor environmental changes through space and time, but also as predictors in species distribution models.

In this review, we identified four datasets (Table 9) showing the global distribution of environment descriptors, of which two have detailed metadata.

Table 9. Global datasets in the 'environment descriptor' category. The factsheet which applies to all datasets in this section is under development. Coloured shading indicate that the datasets are directly downloadable from the *Ocean Data Viewer*.

Dataset title	ID	Metadata	Factsheet name
General Bathymetric Chart of the Oceans (2008)	GEBCO-001		[Environment descriptor]
Bio-ORACLE: a Global Environmental Dataset for Marine Species Distribution Modelling (2012)	Ghent-001		[Environment descriptor]
Mean Sea Surface Productivity in June and December 2003-2007 (2008)	WCMC-020-021	✓	[Environment descriptor]
Mean Annual Sea Surface Temperature 2003-2007 (2008)	WCMC-022	✓	[Environment descriptor]
AquaMaps Environmental Dataset	AquaMaps-003		[Environment descriptor]

Administration

Administrative datasets are essential tools to support spatial analyses of marine and coastal biodiversity, whether it is for impact assessment, or for research and conservation purposes. In this review, we identified eight datasets (Table 10) showing the global distribution of administrative data, of which six have detailed metadata. Factsheets were not created for these datasets because they do not define biodiversity features.

Table 10. Global datasets in the 'administration' category.

Dataset title	Dataset ID	Metadata
Global Self-consistent, Hierarchical, High-resolution Geography Database (2013)	UniHaw-001	✓
Global Maritime Boundaries Database (2008)	GMBD-001	
Global Distribution of Islands (2010)	WCMC-005	✓
Exclusive Economic Zone boundaries (2012)	VLIZ-001	✓
Regional Seas Boundaries (unofficial)	UNEP-002	✓
Boundaries of the Global International Waters Assessment (2003)	UNEP-001	✓
Global Distribution of Regional Fishery Bodies (2010)	FAO-001	✓
Global Distribution of Ports: World Port Index (2011)	NG-AI-001	

4. Data challenges, gaps and limitations in the marine environment

This section provides a discussion of some of the issues faced when using marine data. The discussion covers topics such as the challenges of marine data collection, the different types of data gaps which exist and how these challenges are being overcome. The information provided here is intended as an introduction to the subject rather than a detailed analysis of the problem.

Background

The oceans cover 71% of the Earth's surface and are host to an estimated 50-80% of all life on Earth. They contain some of the most productive ecosystems, vast natural resources and unique habitats, and further play a vital role in regulating the Earth's climate. However, the marine environment is subject to many pressures (UNEP 2006). Fisheries are removing living resources at a rate considered to be unsustainable (Pauly et al. 2002, 2013), while essential habitat is being degraded (by bottom trawling, renewable energy production/extraction infrastructure, underwater cabling, coastal development, aggregate extraction, coastal deforestation, amongst others) and waters are being chemically altered through pollution (including through agriculture runoffs, river discharges and maritime accidents). Furthermore, concern over the impact of climate change on marine ecosystems is increasing (Root et al. 2003), with longer-term shifts in mean environmental conditions and climate variability moving outside the bounds within which adaptations in marine communities have been previously associated (King 2005, Beaugrand 2009). Thus, the changing ocean-atmospheric conditions (including ocean warming and acidification, hypoxia, and ice cover changes) are leading to altered abundances (i.e. population levels) of species, and changing spatial distributions (e.g. Southward et al. 1995, Perry et al. 2005, Beaugrand 2009). In turn, changes at the species level may severely impact the biological and environmental functioning of ecosystems or food webs, the goods and services derived from them, and conservation and resources management.

Why are there data gaps?

Collecting data in the marine environment is challenging

Understanding the impacts of pressures on both marine species and the people that depend on them for food and livelihoods requires substantial data, not only on these species, but also on bio-geochemical and oceanographic processes. However, ocean-based research is expensive and logistically challenging due to the size and remoteness of the biomes[10] and because marine scientists

[10] A biome is a large naturally occurring community of flora and fauna occupying a major habitat (http://www.oxforddictionaries.com/definition/english/biome). Alternative definition at: http://terms.biodiversitya-z.org/terms/29.

must rely on advanced technologies and equipment such as oceanographic research vessels, submersibles, remotely-operated vehicles and remote-sensing (i.e. satellite telemetry, aerial photography) to gather data in the marine realm. These requirements mean that the costs of marine projects typically exceed those experienced by terrestrial ecologists.

Detailed scientific knowledge is still needed

Despite an estimated 2.2 million species living in the oceans, it is thought that 91% of these have not yet been described (Mora et al. 2011). Gaps in taxonomic expertise further hamper understanding of marine biodiversity and limit the discovery of new species. This is particularly the case for cryptic species, those that are morphologically similar but genetically distinct, and those groups that have a large number of rare or less common species, such as bacteria (Figure 1).

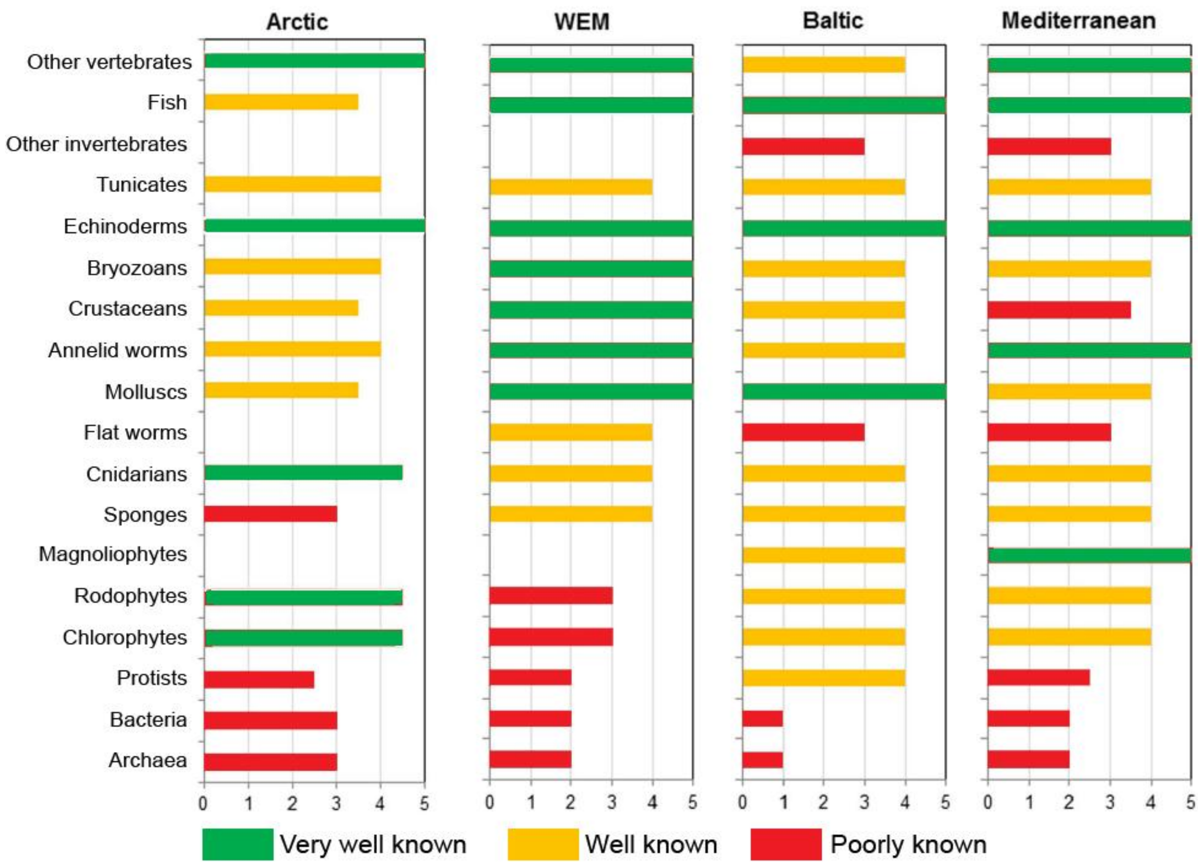

Figure 1[11]. State of knowledge of taxonomic groups ranked from 1 (poorly known) to 5 (very well known) [left blank = not assessed/not applicable] in the Arctic Sea, western European margin (WEM), Baltic Sea and Mediterranean Sea (adapted from: Narayanaswamy et al. 2013). Sources: B. Bluhm pers. Comm.; (Narayanaswamy et al. 2010, Ojaveer et al. 2010, Coll et al. 2010, Danovaro et al. 2010).

Significant time is also needed to carry out adequate species identification, either on-board research vessels, or after the survey for those specimens that can be preserved (e.g. eggs/larvae of large species, or small species such as invertebrates). Finally, species identification, which includes the

[11] Source: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0058909.

description of previously unknown species, usually requires specialist skills (e.g. taxonomy, bioinformatics) and/or equipment (e.g. microscopy, digital imagery analysis, genetic analysis).

Types of data gaps

The challenges associated with collecting and interpreting data on the marine environment therefore often lead to limitations in marine datasets. Accurate, reliable data on the marine environment are frequently scarce, with errors stemming from the low 'detectability' of species[12], species misidentification, and sampling bias[13]. Data frequently show bias in terms of spatial and temporal coverage. For example, if only part of a particular habitat (or environmental gradient) has been sampled for a particular species, spatial coverage is incomplete: this means that observed data on this species may not be a representative sample of locations where that species actually occurs. The following examples illustrate key gaps in data coverage and understanding in the marine environment. These challenges and characteristics should be taken into account when using data to avoid incorrect conclusions being drawn.

Spatial and temporal data gaps

It is estimated that 95% of the ocean remains unexplored, with a strong bias in sampling effort and data availability towards temperate regions in the Northern hemisphere, such as the North Atlantic Ocean (Figure 2). In particular, most records for marine species have been obtained from within the exclusive economic zones[14] of Canada, Australia, Alaska, United Kingdom, United States of America, Greenland, Republic of South Africa and Bermuda (Mora et al. 2008). Although tropical areas are known to be species rich, data on the species inhabiting them is amongst the poorest (Mora et al. 2008).

[12] Low detectability in an occupied habitat patch is a common sampling problem when a population size is small, individuals are difficult to sample, or sampling effort is limited (Gu & Swihart 2004).
[13] Sampling bias is consistent error that arises due to a sample not being selected in a random manner.
[14] Exclusive Economic Zones (EEZ) are waters generally up to a distance of 200 nautical miles from a country's coastline.

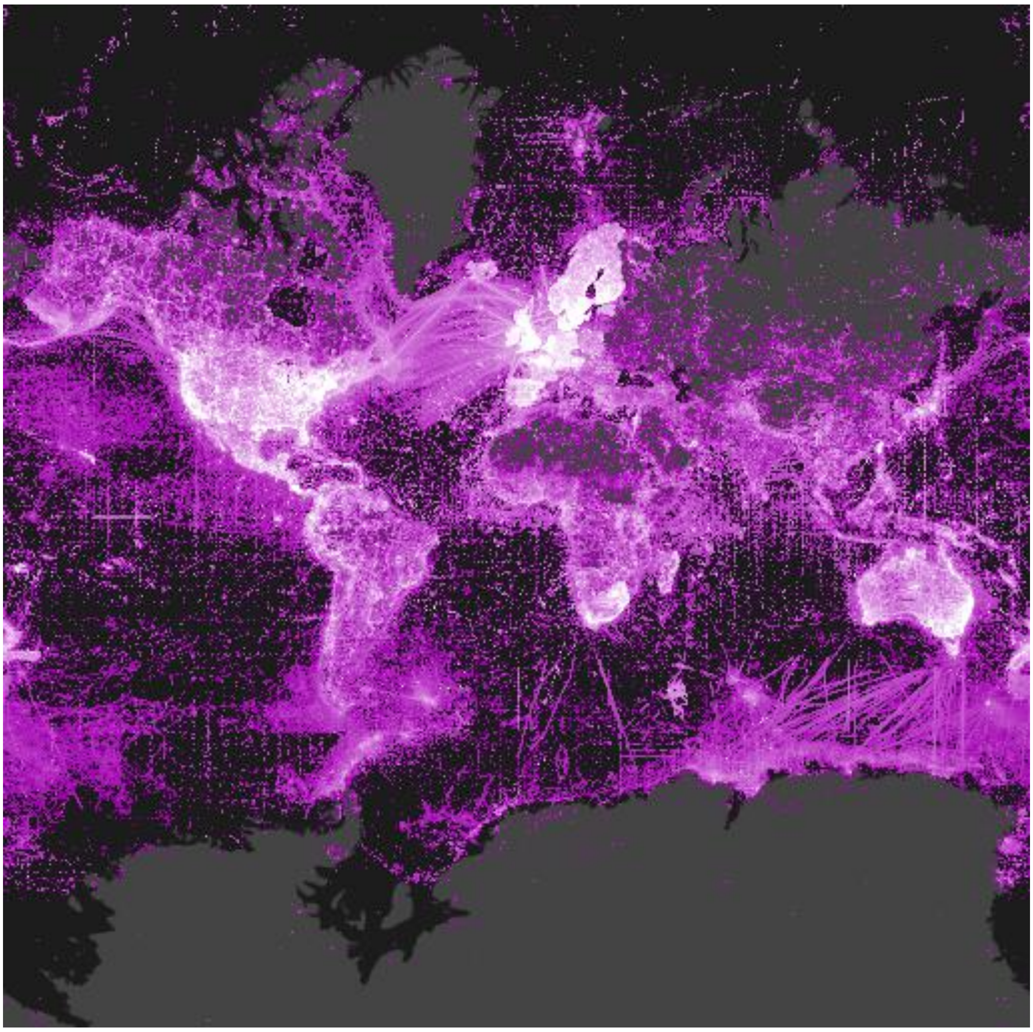

Figure 2[15]. Map showing species occurrence records published in the Global Biodiversity Information Facility (GBIF) network on 30 April 2014 (437 million occurrences from almost 1.5 million species and 602 publishers).

Even within a given animal group, geographic coverage can be heterogeneously distributed. Based on a database of 430 cetacean surveys conducted worldwide from 1975–2005 (Kaschner et al. 2012), Figure 3 illustrates the spatial bias in survey effort, which was found to be mostly concentrated in the northern hemisphere, particularly in waters under US and northern European jurisdiction. This study also showed that, for cetaceans, less than 25% of the world's ocean surface had been surveyed, with almost half the global survey effort (defined as total area, in km^2, covered by all survey study areas across time) being concentrated in the eastern tropical Pacific.

[15] Source: http://www.gbif.org/occurrence.

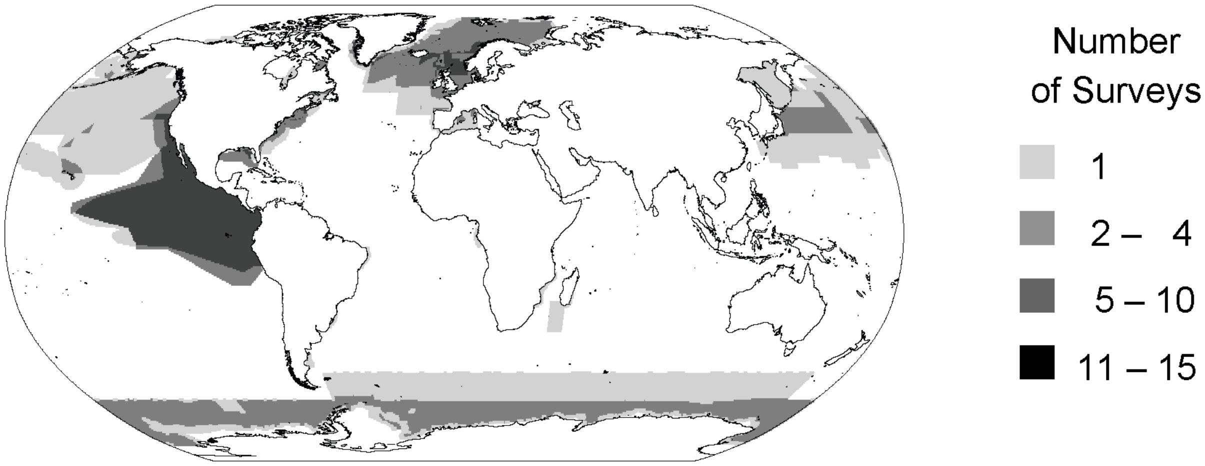

Figure 3[16]. Cetacean line-transect survey effort in terms of frequency of coverage (Kaschner et al. 2012).

Data availability within geographic regions varies considerably depending on the oceanic compartment considered (Figure 4). For example, there are many more records on marine species available from the continental shelf and slope, and from coastal and surface waters, due to their better accessibility and higher productivity. The deep sea and more generally marine areas beyond national jurisdiction remain comparatively unexplored due to the logistical challenges and cost associated with sampling there (Mora et al. 2008).

The development status of countries and/or their political stability level can also play a role in the level of sampling in the waters under their jurisdictions. Figure 5 illustrates this for the Mediterranean Sea, where the northwest-southeast divide is highlighted in terms of data gaps for seagrass: most North African countries (except Tunisia) and most eastern European countries (and Turkey) have under-sampled coastlines or not sampled at all for the species of seagrass considered.

[16] Source: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0044075

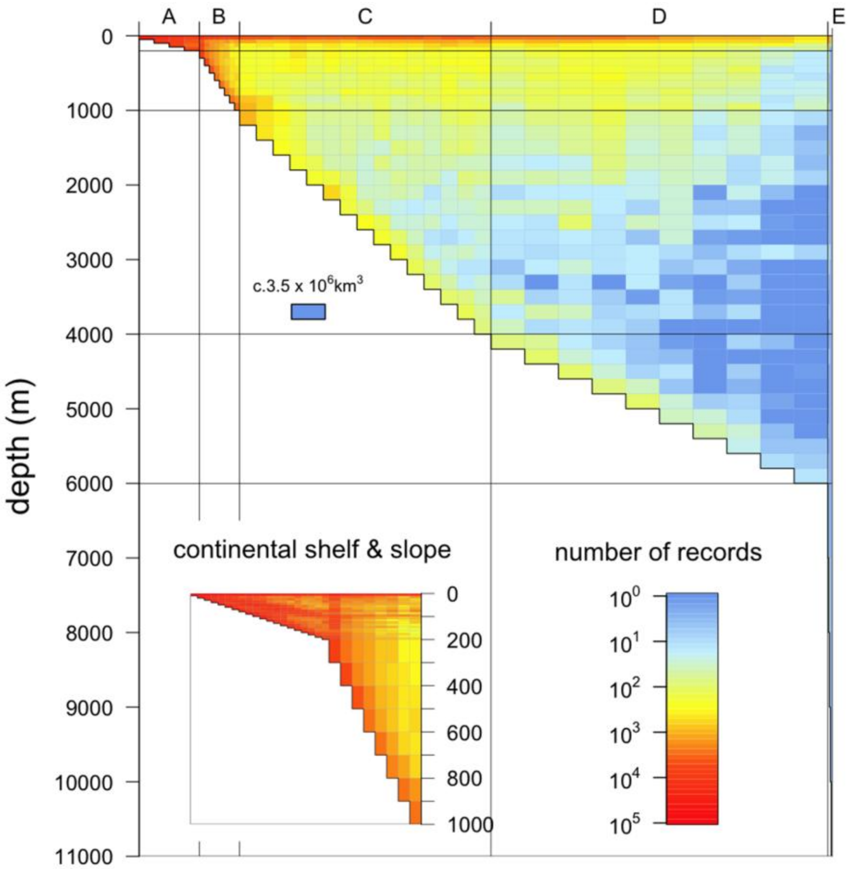

Figure 4[17]. Global distribution within the water column of recorded marine biodiversity (Webb et al. 2010). The horizontal axis splits the oceans into five zones on the basis of depth, with the width of each zone on this axis proportional to its global surface area. The vertical axis is ocean depth, on a linear scale. This means that area on the graph is proportional to volume of ocean. The inset shows in greater detail the continental shelf and slope, where the majority of records are found.

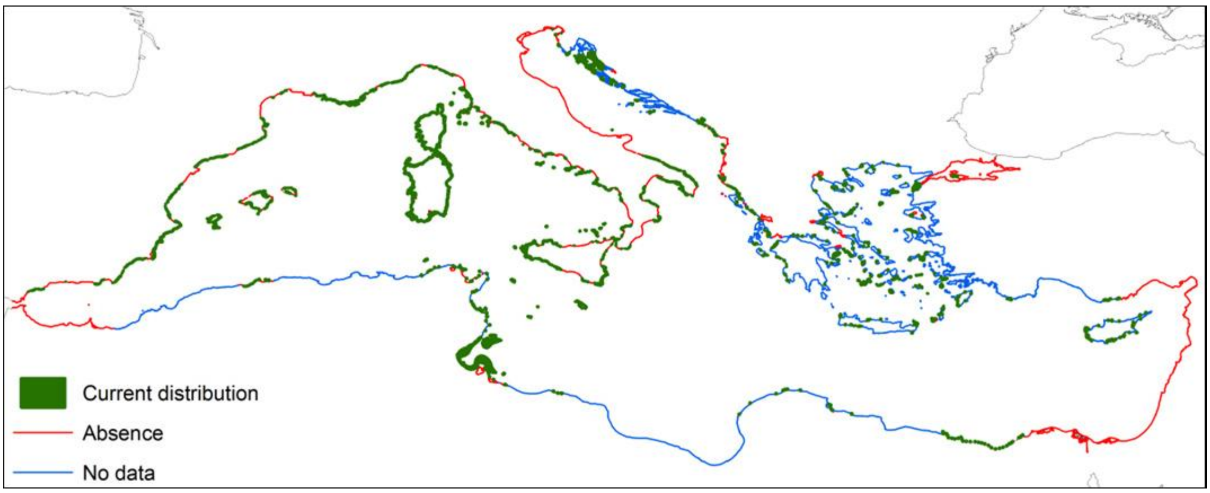

Figure 5[18]. State of knowledge of the distribution of *Posidonia oceanica* seagrass across the Mediterranean Sea (Belluscio et al. 2013), where presence ("current distribution", in green), absence ("absence", in red) and data gaps ("no data", in blue) are shown.

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[17] Source: http://www.ploscollections.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0010223

[18] Source: Mediterranean Sensitive Habitats (MEDISEH) project; http://mareaproject.net/contracts/5/reporting/.

Temporal data gaps also exist as exemplified by records from the OBIS-SEAMAP[19] project, which has acquired and served marine mammal, seabird, and sea turtle data to the public since its inception in 2002. Records collected during the autumn and winter were comparatively less frequent than those collected in spring and summer (Figure 6) as a result of temporal sampling bias (Kot et al. 2010).

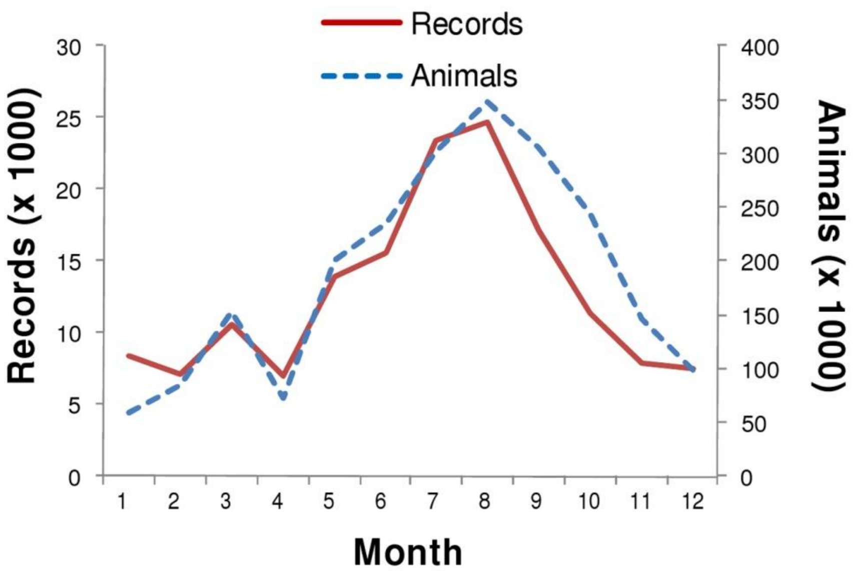


Figure 6[20]. The number of records and animals published on SEAMAP each month for marine mammals (Kot et al. 2010).

Temporal biases in data collection can significantly influence our knowledge of species with seasonal distribution patterns linked to e.g. foraging and breeding. If a foraging area is surveyed when such a species has left for its breeding sites, then the data collected would incorrectly suggest that the species is absent from studied area. It should also be noted that datasets compiled from several sources (such as global online data repositories), opportunistically sampled (such as citizen science programmes, or bird and marine mammal observations on research vessels), and small datasets (such as those for rare or elusive species) are particularly subject to issues of data quality. In these cases, skewed distribution of sampling effort, be it spatially or temporally, may lead to sampling bias, while outlying data points will also contribute large errors in small datasets.

Species data gaps

In addition to the lack of knowledge about marine species there is also a bias in knowledge and data availability of particular animal groups. For example, nearly half of known marine biodiversity is represented by only three groups (crustaceans, molluscs, and fish), and many of these species are commercially important (Intergovernmental Oceanographic Commission (IOC) of UNESCO 2014). However, even charismatic marine groups, such as sharks and seahorses, lag behind terrestrial

[19] Ocean Biogeographic Information System – Spatial Ecological Analysis of Megavertebrate Populations project; http://seamap.env.duke.edu/.

[20] Source: http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0012990

groups in the extent of knowledge on their constituent species and the threats they face. For example, a study found that 31% of sharks, skates and rays and 66% of seahorses lacked sufficient data to undertake an assessment of extinction risk (McClenachan et al. 2012). Deep-sea habitats such as hydrothermal vents and cold seeps are presently under-studied, and so are the plethora of endemic species currently unknown to science that they tend to host.

To date, only 8,171 marine species have been assessed under the IUCN Red List criteria for threatened species (IUCN 2013), i.e. 0.37% of the estimated 2.2 million marine species on the planet. IUCN are not aiming for full assessment of all species on Earth, rather a representative sample of around 8% of all species (Stuart et al. 2010). Even so, the marine environment is recognised by IUCN to be lagging behind the terrestrial realm and it is a target for further work. Furthermore, although 6,755 (83%) of the assessed marine species have associated expert-derived range maps, these maps do not incorporate information on relative occurrence probability, abundance or ontogeny[21] (this is also the case for terrestrial species). It is hence difficult to estimate the likelihood of encounter or population levels in a given location from these maps alone; nor is this their intended use.

Solutions

Addressing spatial and temporal data gaps using models

As a result of the data gaps described above, studies of marine biodiversity and habitats are frequently based on incomplete data, which can lead to skewed or biased interpretation. Consequently, modelling techniques have been developed to gain understanding of distributions and characteristics in the marine environment and the species that inhabit it. A model is a representation of a system, object or event that frequently includes mathematical descriptions and may be used to gain understanding of that system. For example, models representing ecological systems may vary in scale from an individual population, or species, to an ecological community or a climate system. Altering the description of the system, such as by altering the factors, or variables, included in a model allows its sensitivity to changes in particular components to be explored. This may allow key influencing factors, and the interactions between them, to be determined. Models may be tested and validated by comparing their outputs with observed measurements or the results of repeatable experiments, with lack of agreement frequently leading to model development and refinement as better understanding of the system being modelled is gained.

Species distribution modelling

Species Distribution Modelling (SDM) techniques (Guisan & Thuiller 2005, Martinez-Meyer 2005, Franklin 2009) have emerged as pragmatic and cost-effective solutions to “filling in” the data gaps mentioned above using predictive mapping. Species distribution models (Figure 7) are based on physical and environmental “predictive” variables (such as water temperature, salinity, seabed type, depth, nutrient concentration) that are typically cheaper and quicker to record and map across vast

[21] Ontogeny related to the origin and development of an individual organism from embryo to adult forms.

expanses (i.e. regional seas, global scale) than comprehensive species distribution. Species distribution models associate species presence or density (and where available absence) information with the particular environmental conditions at these locations, thereby indicating the species' preferred range for each predictive variable. By examining the values of each physical and environmental variable at un-sampled locations, a species' potential distribution[22], or range, may then be modelled as the relative suitability of environmental characteristics that would either limit or support it at a particular location. In simple terms, a model allows for example, the ability to predict the relative probability of occurrence of a species based on the value of environmental and physical variables at that location. A range estimate may thus be obtained for areas which have not been sampled for that species, thereby 'filling in' the gaps in knowledge. Modelling is particularly useful for species for which little data are available, although it should be recognised that the quality of the available data may limit the predictive power of the model.

Range predictions, or relative suitability maps can then be validated, for example by retaining some of the species occurrence data for model testing, or by carrying out targeted ground-truthing, for example by using dedicated field surveys. Some models can also be refined using expert opinion, or be updated as more occurrence data become available. Validation procedures allow assessing the level of confidence in the modelling results, in lieu of systematic and exhaustive surveys that are rarely a realistic option.

It is worth keeping in mind that the certainty of the occurrence of a given species in a given location cannot be absolute, but model outputs can be very informative in providing for instance a gradation of likelihood of occurrence of a given species in areas where dedicated field surveys have not yet taken place. For instance, it is possible to delineate the 'core habitat' of a species by retaining only predicted occurrence values above a given threshold, thereby identifying the specific areas where occurrence is predicted to be particularly common. Modelling approaches can also be adjusted to look at seasonality patterns of migratory species, or to indentify congregatory areas.

[22] The *potential* distribution of a species represents areas where a species could be present, due to environmental conditions being suitable for its survival and/or reproduction, but may not actually occur due to for e.g. biotic interactions with other species (such as competition) or depletion of the population through human impacts. This contrasts with the *realised* distribution of a species, which refers to areas where it actually occurs.

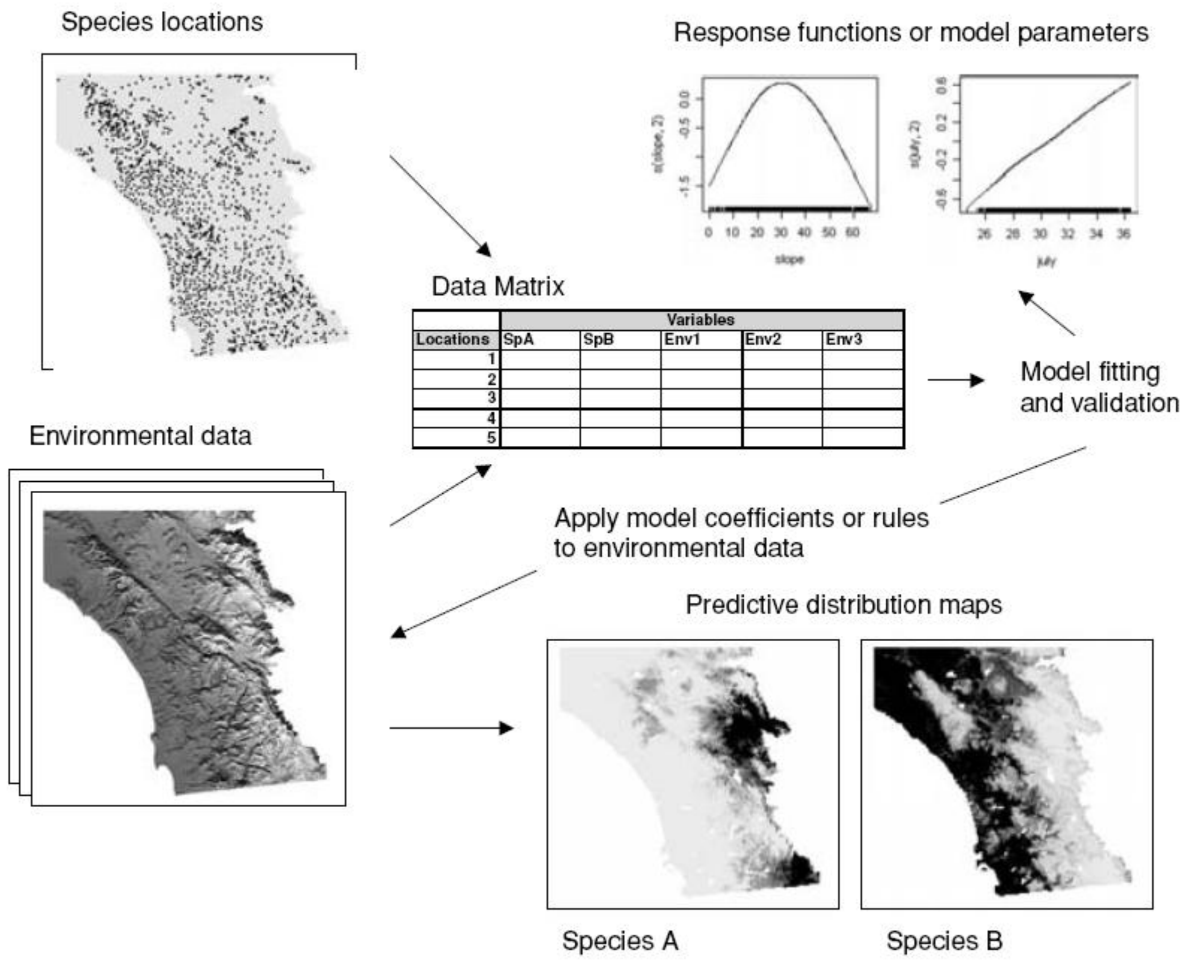


Figure 7. The steps in Species Distribution Modelling (SDM) and predictive mapping (Franklin 2009). Species occurrence data are linked with environmental and physical information, and this relationship is used through modelling to generate continuous distribution maps showing e.g. the relative probability of occurrence of a species across a given area. Image courtesy of Cambridge University Press.

Models also allow the simulation of ecological processes and systems over large periods of time, or under alternative future scenarios of change from that which is currently observed. A scenario is described as a narrative or storyline which provides a powerful tool in developing an understanding of a range of options or plausible alternative futures (Haward et al. 2012). Rather than focussing on accurate prediction, scenarios enable a variety of futures to be considered and explored (Peterson et al. 2003). For example, scenarios may be developed to assess the potential change in climate resulting from a range of greenhouse gas emissions scenarios, and the resulting changes in species distributions. Models thus enable researchers to simulate large-scale experiments that would be too costly or unethical to perform on a real ecosystem, with the studying of inaccuracies allowing hypotheses to be made about possible ecological relations that are not yet known or well understood. Due to the imperfect knowledge of the environment and environmental change in many circumstances, they also aid decision-making and strategic formulation of policy under social and environmental change. Although testing the prediction of systems under conditions that have not yet occurred, such as under climate change, is difficult, models may be tested by projecting under previously known conditions (hindcast modelling) or several alternative models may be used to explore and understand the range of uncertainties in model outcomes.

Using data

What does the 'absence of data' mean?

How data are recorded may influence their reliability and subsequent use (e.g. in models, impacts assessments). For example, caution should be taken when using species spatial distributions that have been estimated using data that were not obtained using comprehensive survey and sampling strategies. In this context, it is imperative to discriminate between 'no recorded presence' and 'identified absence'.

During a desktop study (e.g. for an environmental impact assessment), failure to find a record a species at a particular location may mean that:

1. no sampling has taken place at this location;
2. the habitat is not suitable for this species to live, or the habitat is suitable but, due to other factors such as biotic interactions with other species (competition, predation), the species does not generally occupy this habitat;
3. the sampling/survey strategy was not adequate (e.g. wrong time of day for species showing diurnal movements; wrong time of year for species showing seasonal migrations; sampling gear unsuited to the target species, patchy spatial distribution missed by the survey path, etc);
4. the species was misidentified as being another species;
5. the species is rare/elusive meaning that it was not detected, though present; and/or
6. observed data were not shared (e.g. with online databases) or published (in the grey or peer-reviewed literature).

In the marine environment, where detection probabilities are generally low, obtaining valid 'absence data' remains difficult and rare, and observations may therefore represent the minimum area inhabited by a particular species. As a result, species absence records are usually only available at a limited number of sites, because the absence of a species is only ascertained when a given site has been exhaustively explored. Figure 5 presents the result of the collaborative work of over thirty scientists as part of a Mediterranean-wide research project (Giannoulaki et al. 2013). Using available occurrence data from various sources (including published and unpublished observation data) and local expertise on the habitat preference of *Posidonia oceanica*, an endemic species of seagrass, it was possible to create a map showing 'presence' and 'absence' areas for this species across the Mediterranean basin, as well as areas where data were lacking.

Such a "presence-absence" map is infrequent and comparatively more informative than the commonly available "presence-only" maps as it clearly highlights spatial data gaps. The most common form of species data available at large-scale in the marine environment frequently is presence-only data, as exemplified by museum collections and online data repositories, such as the Ocean Biodiversity Information System (OBIS) (Intergovernmental Oceanographic Commission (IOC) of UNESCO 2014). As Species Distribution Models based on presence-only data are inherently less powerful than those based on presence-absence data, the collection of absence data through systematic surveys should be encouraged.

Data format matters

Marine and coastal datasets exist in numerous formats, and are most commonly distributed as point or polygon vectors (i.e. shapefiles) and rasters (which are grids of pixels of varying resolution), showing areas of presence of species and habitats. As discussed above, information on the real absence of the species or habitat in specific areas (as opposed to the absence of data) are rarely included in the datasets.

The spatial occurrence of species and habitat are often represented using polygon (i.e. boundary) data that show the 'extent of occurrence', i.e. the limits of distribution in a given area. This is different from the 'area of occupancy', which is the fine-scale locations at which a species actually occurs. If, for example, the presence of a species is represented as a set of polygons, and sites within the polygons have in reality only been sparsely sampled, this might obscure the fact that the species is restricted to only a handful of sites within these polygons. In this case, as the species does not occupy all the spaces within the polygons, point data would give a more accurate portrayal of actual occurrence.

When the aim is to calculate the spatial coverage (e.g. surface area in km^2) of a habitat (e.g. seagrass meadows, mangrove forests) in a particular region, polygon data are logically more appropriate than point data, assuming that the habitat is continuously present within the boundary of the polygons. Point locations are however easier to collect than actual boundaries, meaning that point data remain a common data type, even when polygon data would be more appropriate. Some datasets, such as the seagrass layers[23] of the *Ocean Data Viewer*, are hence available as polygons and points, which should be displayed together (Figure 8). Habitats that are difficult to sample such as deep-water vents and seeps are generally available as point datasets. The May 2014 release of the World Database on Protected Areas (IUCN & UNEP-WCMC 2014) had 92% of protected areas as polygons and the remainder (8%) as points. For the latter, it is possible to artificially create a buffer around the point location, based on surface area information (where available), but this cannot be a true representation of the actual protected area boundaries.

[23] http://data.unep-wcmc.org/datasets/9 (points), http://data.unep-wcmc.org/datasets/10 (polygons).

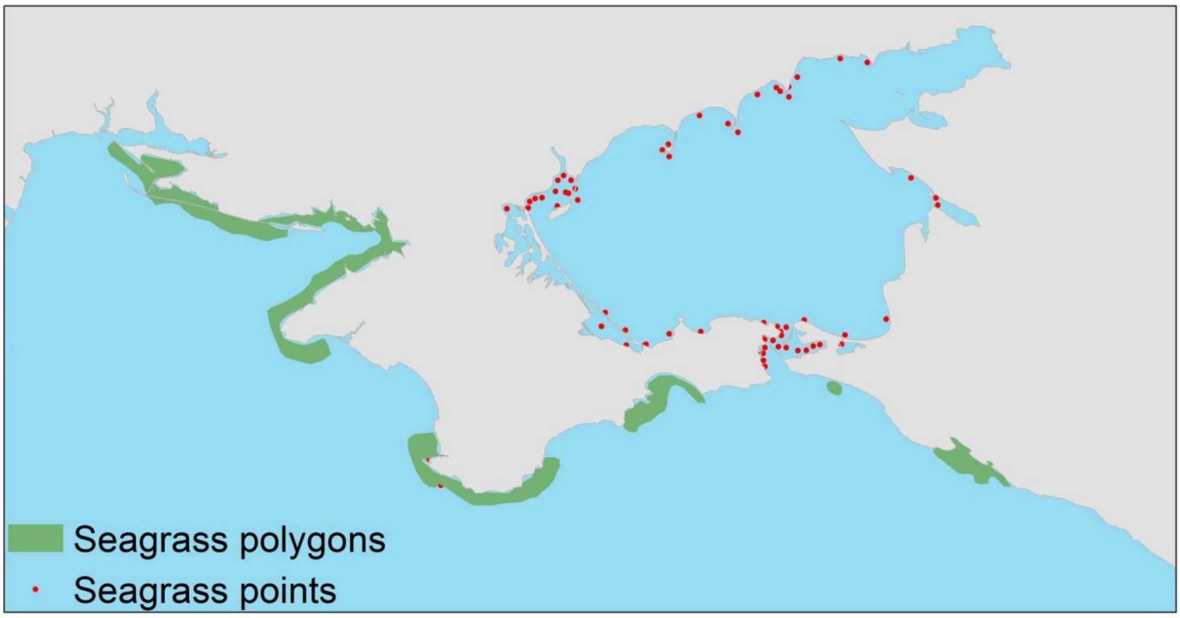


Figure 8. Distribution of seagrasses in the Northern Black Sea region (Green & Short 2003, UNEP-WCMC & Short 2005), illustrating the point and polygon subsets of the dataset.

Spatial and temporal scales of datasets

A consideration relating to data accuracy and uncertainty is consistency of temporal and/or spatial scales. Data must be at an appropriate scale to answer a particular question, as patterns observed at one scale (e.g. global, monthly) may not be detectable at another (e.g. local, annual). Different datasets that are combined for an assessment or model must also be at compatible scales. It would, for example, be inappropriate to model a species' preferred habitat if species and environmental data were collected in different time periods. If species occurrence data recorded at a fine spatial resolution are combined with sea surface temperature at a much coarser spatial resolution covering a steep environmental gradient, an estimate of preferred temperature range may be much broader than in reality.

Such temporal and spatial mismatches are not infrequent when considering datasets that are particularly time-consuming or expensive to acquire, and therefore are not frequently updated and may not present consistently fine spatial resolutions. Global-scale biodiversity datasets unfortunately often fall in this category, meaning that any use of the data must take into account the age of the dataset.

Understanding the age of the dataset is particularly important for species whose ranges might have shifted through time with temperature patterns, or habitats that might have regressed due to anthropogenic pressure (e.g. pollution) or natural causes (e.g. storms). Consistency of time-scale may thus be particularly important for mobile species with particularly restricted habitat requirements, or for those that show seasonal changes in preferred habitat. Many of the highly migratory baleen whales, such as sei whales (*Balaenoptera borealis*), travel from warm latitude tropical waters in the winter to their feedings grounds in cooler polar waters in the summer. A distribution model based on a mean annual temperature envelope may therefore be unable to accurately determine the species' regular occurrence in tropical (winter time) and polar (summer time) areas because the whale is found at a wide range of temperatures depending on the season.

Data developments

Despite the uncertainties and knowledge gaps surrounding species and habitats, knowledge of the marine realm is increasing. For example, in 2000, a ten year global scientific partnership was developed to address marine knowledge gaps. This project, the Census of Marine Life[24] involved 2,000 scientists in more than 80 countries worldwide. It was thus able to tackle questions of diversity, distribution and abundance at a global level, establishing a current baseline against which changes could be compared. In addition, the project greatly improved access to data and information on the oceans, as well as tools and capacity for monitoring. The increase in, and collation of, data that the Census of Marine Life involved also helped researchers and policymakers identify relatively unexplored regions and knowledge gaps.

To try to further address some of these gaps, the initiative Life in a Changing Ocean[25] was recently instigated, the goal of which is to advance discovery and expand marine biodiversity knowledge to support healthy and sustainable ecosystems through an integrated global view of marine life. It is hoped that it will address knowledge gaps and answer the questions needed to effectively manage and sustain ocean ecosystems.

Accessibility to data on marine species is further being advanced by online databases such as FishBase[26], SealifeBase[27], OBIS and AquaMaps[28], which make local and regional observation data, species characteristics and life history data and modelled distribution maps available worldwide. Despite these valuable resources, it is likely that much more data exist which have been obtained through private funding, for example as part of environmental impact assessments, and are therefore not accessible to the public.

In an environment as extensive, inaccessible and changeable as the world's oceans, there will always be gaps in data and knowledge. It is therefore vital that data improvement and provision are encouraged, including through innovative ways such as “citizen science”, whereby the wider public can help collect new data but also validate existing datasets. UNEP-WCMC has hence recently produced a habitat validation tool that can be used to ground truth mangrove and coral datasets derived from satellite imagery[29]. Regardless how they are collected, data must be accompanied by an awareness of their potential uses, limitations and the gaps within them that might affect their reliability and suitability to answer specific questions and promote understanding.

[24] www.coml.org
[25] http://lifeinachangingocean.org
[26] www.fishbase.org
[27] www.sealifebase.org
[28] www.aquamaps.org
[29] http://validation.unep-wcmc.org.

Annex 1. Background factsheets

To date, ten background factsheets are available. More of these will be provided in future updates of this document.

Warm-water coral reef

Polyps of star coral, family Dichocoenia. Copyright: A. Gibson, 1971 (Image ID: 93472663). Used under license from Shutterstock.com

Corals are composed of many individual coral polyps. A coral polyp is a relatively simple organism, typically composed of a small cylindrical body, topped with a ring of tentacles which are used to capture food from surrounding water. Polyps are animals of the class Anthozoa, which also contains sea anemones and sea pens. Animals in this group are generally sedentary (Segar 2012). A large number of corals have evolved to build large colonies based around a communal skeleton. Reef-forming corals (scleractinians) are those that lay down stony skeletons of calcium carbonate for protection and support which can take various structural forms

Geographic distribution

Warm-water coral reefs are highly restricted in their geographic distribution, needing areas of warm, shallow, clear waters to produce the copious quantities of limestone necessary for reef formation. Warm-water coral reef species diversity is concentrated in the central Indo-Pacific (the “Coral Triangle”), and decreases with increasing distance from the Indo-Australian archipelago (Hughes et al. 2002). Due to their restricted distribution, coral reefs occupy an area of only 260,000 - 600,000 km^2, less than 0.1% of the Earth’s surface, or 0.2% of the ocean’s surface (Reaka-Kudla 2005).

Ecology

Warm-water corals have a symbiotic relationship with algae called zooxanthellae. The algae provide the coral with nutrients derived from photosynthesis, and oxygen. The coral polyp provides the algae with a place to live along with waste products of respiration (carbon dioxide) which are used by the algae in photosynthesis. This symbiotic relationship is why corals live in shallow waters, allowing the algae access to the sunlight in order to photosynthesise.

The zooxanthellae algae provide the coral with colour. When the coral is stressed, it can expel the algae, in a process called 'coral bleaching'. This leaves the coral looking white because the polyp is mostly transparent and the coral skeleton is white. Coral starves without the zooxanthellae and so, if the stress events continue, it can die. However, if the stress is short-lived the coral can regain their zooxanthellae and survive (Diaz-Pulido & McCook 2002).

Warm-water coral reefs are the most biodiverse of marine habitats per unit area, with diversity comparable to rainforests but an area only 5% of the size (Reaka-Kudla 1997, Knowlton et al. 2010). Most of this diversity is not due to the corals themselves (there being fewer than 1,500 species of stony corals; Kitahara et al. 2010) but rather due to the multitude of organisms that depend on the coral reef ecosystem (Knowlton et al. 2010). Reef species diversity has indeed been estimated at anywhere from 600,000 to more than 9 million species worldwide (Plaisance et al. 2011). In addition, coral reefs are considered to be among the most important ecosystem engineers found in the marine environment (Jackson 2001). Ecosystem engineers play key roles in ecosystem organisation by providing conditions or resources essential for species to complete their life cycles or by helping to maintain niche diversity such as by providing complex habitat structures (Keith et al. 2013). The habitat complexity provided by reefs may be the reason for their high biodiversity and their role as evolutionary engines, acting as 'cradles' of speciation. Shallow water coral reefs provide a beneficial environment for evolving new species, which then expand to new environments in the ocean (Kiessling et al. 2010). These key functions of coral reefs make them disproportionately important in comparison to their global footprint.

Coral reefs are the preferred habitat of a number of Critically Endangered and Endangered species, for example the fish species humphead wrasse (*Cheilinus undulates*) and Banggai cardinal fish (*Pterapogon kauderni*) (IUCN 2013). Some Critically Endangered and Endangered species also depend on coral reef fish as food during key stages of their life cycle, for instance pups and juveniles of the Endangered shark scalloped hammerhead (*Sphyrna lewini*) (IUCN 2013).

Economic & societal value

Coral reefs provide numerous benefits to those who live locally to them and to the international community. At a local scale, coral reefs provide food and livelihoods. Reef-associated fish are a key source of protein in developing countries (Bullock et al. 2001, Tsounis et al. 2014). Reefs provide a number of physical functions such as storm protection by attenuating waves (reducing the wave height and energy). As a result, reefs provide support for mangrove and seagrass habitats by reducing the sea's energy levels close to shore (Moberg & Folke 1999, Burke et al. 2011).

Two of the most visible benefits of coral reefs are tourism and the inspirational qualities of the habitat. Films, books and posters have all depicted the colourful and energetic reef environment (Moberg & Folke 1999). These visuals have fuelled natural history programmes and provided the general public with insight into this world. As a result, coral reef tourism has grown and provides substantial income in some parts of the world (Brander et al. 2007).

Threats

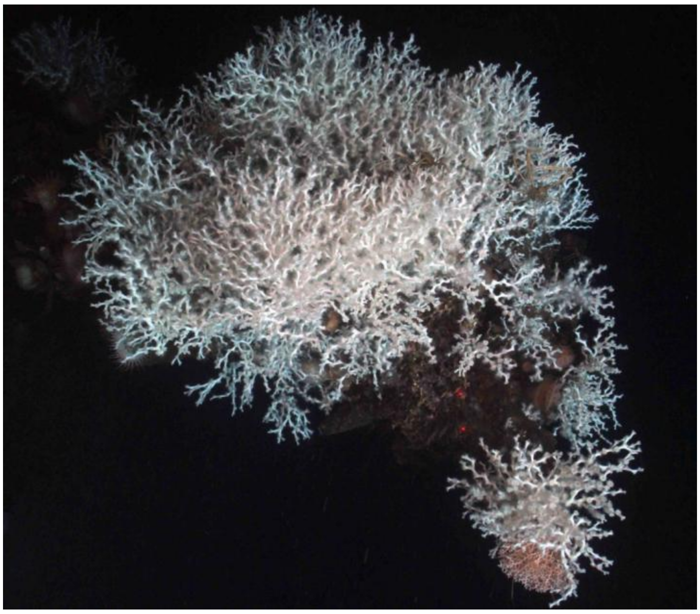
Reefs are also one of the most endangered habitats on the planet (Bellwood et al. 2004), facing dramatic declines in abundance as a result of bleaching and diseases driven by elevated sea surface temperatures, with extinction risk further exacerbated by local-scale human disturbances including coral mining, agricultural and urban runoff, pollution, damaging fisheries and the introduction of damaging invasive species. There is frequently a direct correlation between declining reef health and increasing human population, mainly due to pollution and over exploitation (Burke et al. 2011). Destructive fishing practices are a particular problem, with poison such as cyanide being used for live capture of fish for both restaurants and the aquarium trade. Blast fishing is also very destructive, whereby explosives are used to stun schools of reef fish and cause huge damage to the reef, shattering the structure and killing many non-target species (Cesar 2002). Once the complex reef structure is damaged or destroyed, the niches which provide homes and shelter for the array of species are lost.

International threat status

The proportion of corals threatened with extinction has increased dramatically in recent decades and exceeds that of most terrestrial groups, with one-third of reef-forming corals facing elevated extinction risk from climate change and local impacts (Carpenter et al. 2008). Specifically, 25 reef-forming coral species are listed as Endangered by the IUCN Red List of Threatened Species, and five are listed as Critically Endangered (IUCN 2013). Conserving coral reef biodiversity and the capacity of reefs to generate essential services to local people is a global priority (Moberg & Folke 1999), and coral reefs are increasingly the focus of biodiversity conservation prioritisation schemes. They are included in the rationale for Key Biodiversity Area and marine protected area designation, e.g. the Great Barrier Reef Marine Park.

Last updated: February 2014

Cold-water coral



Down-looking mosaic of *Lophelia*. Gulf of Mexico.
Credit: Lophelia II 2010 Expedition, NOAA-OER/BOEMRE[30].

There are four main groups of cold-water corals: (1) stony, i.e. reef-forming, corals (scleractinians), (2) soft corals (also named octocorals due to their 8-fold symmetry), (3) black corals (anthipatharians) and (4) hydrocorals (stylasterids) (Roberts et al. 2006). Cold-water corals are different from their warm-water counterparts because they do not contain symbiotic algae for photosynthesis and grow more slowly. Cold-water corals obtain all their energy from organic matter and zooplankton, which they catch from the currents drifting past (Freiwald et al. 2004). These communities can create a heterogeneous structural biogenic habitat which can take on a diverse range of forms, of varying density and reaching heights of several metres above the seabed (Freiwald et al. 2004, Stone 2006). The principal ecological aspects of cold-water corals are only beginning to be understood as the technology to explore deep-water environments has advanced significantly in the last decade.

Geographic distribution

Cold-water corals can be found over a wide range of latitudes, from tropical to polar regions, and from the shallow to the deep seas. Their distribution is largely defined by water temperatures, which must generally be between 4° and 12°C. At high latitudes, these conditions are generally found in relatively shallow waters (approximately 50 to 1,000 m), and at low latitudes they are present at great depths (up to 4,000 m), beneath warm water masses (Roberts et al. 2006). Compensating for knowledge gaps posed by the relative inaccessibility of cold-water corals, substantial progress in mapping cold-water coral distribution has been achieved through the use of species distribution models (Tittensor et al. 2009, Davies & Guinotte 2011, Yesson et al. 2012).

[30] Source: http://www.flickr.com/photos/noaaphotolib/5277256119/

Ecology

Despite suffering from a lack of observed information on both distribution and diversity, cold-water corals are arguably one of the most three-dimensionally complex habitats in the deep sea. Cold-water corals can occur as isolated colonies (i.e. small patches of free-living individuals), or they can form large reefs covering up to several kilometres, or even massive carbonate mounds up to 300 m in height (Roberts et al. 2006). Although octocorals are not reef-forming, they can form complex single- or multi-species assemblages, particularly in combination with the other three groups of cold-water corals.

They are certainly unique ecosystems in terms of being 'ecosystem engineers' that provide habitat structure (e.g. feeding and nursery grounds) for other organisms, including specialist fauna, in the deep ocean (Fosså et al. 2002, Roberts et al. 2009). Ecosystem engineers play key roles in ecosystem organisation by providing conditions or resources essential for species to complete their life cycles or by helping to maintain niche diversity such as by providing complex habitat structures (Keith et al. 2013). For instance, up to 1,300 associated species have been found living on *Lophelia pertusa* reefs (Roberts et al. 2006), and cold-water coral reefs may also be associated with a distinctive fauna (Henry & Roberts 2007).

Like their warm-water counterparts, deep-sea coral communities support a large number of other marine species, such as bristle worms, crustaceans, molluscs, starfish, sea urchins and fish. It has been suggested that cold-water coral biodiversity may be comparable to that found on warm-water coral reefs although, for practical reasons associated with the difficulty in sampling deep sea areas, few quantitative studies of ecosystem function and regional comparisons have been possible (Roberts et al. 2006). It is likely that many species unknown to science will be discovered in years to come.

Economic & societal value

While it is unlikely that many people will see cold-water corals first hand. Unlike tropical coral reefs, there is interest in their existence, based on the popularity of programmes about the marine environment that provide evidence of the appeal of this ecosystem (Beaumont et al. 2007).

The ability of cold-water corals to provide heterogeneous structure which supports other species has considerable value in terms of their place in the wider ocean habitat. Their provision of habitat niches for commercially fished species is also of high importance (UNEP 2007).

Threats

Cold-water corals are fragile and extremely slow-growing (with some reefs being tens of thousands of years old), making them particularly vulnerable to disturbance and environmental change, for instance deep-water trawling and ocean acidification (Roberts et al. 2006). Despite the depth at which these ecosystems are found, there is significant evidence of human activities in the majority of surveys which have been undertaken (Freiwald et al. 2004). Bottom fisheries are one of the greatest threats to this habitat because of heavy gear may cause hundreds of years worth of damage when it comes into contact with the slow-growing reefs (Freiwald et al. 2004). Other threats include oil and gas extraction, cable and pipeline placement and mineral exploration.

In addition to direct damage and clogging with silt from fisheries activities, ocean acidification is a problem. Ocean acidification is caused by increased concentrations of carbon dioxide in the Earth's atmosphere (Cooley et al. 2006). Changes in carbon dioxide concentration and that of other gasses in the Earth's atmosphere lead to changes in chemistry of the ocean through air-sea gas exchange (Guinotte & Fabry 2008). These changes result in elevated acidity in the ocean, which is a direct threat to corals as it can lead to corals being dissolved by the water around them (Turley et al. 2007). Finally, slowed growth and increased fragility are also consequences of ocean acidification (Guinotte & Fabry 2008).

International threat status

The vulnerability of these slow-growing delicate structures, combined with the high levels of biodiversity they may promote, make them an important focus for marine conservation. Cold-water coral species, however, have not yet been assessed under the IUCN Red List of Threatened Species (IUCN 2013). Also, there is limited information on the biodiversity levels associated with cold-water coral reefs, though it is likely elevated relative to the surrounding habitat.

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Mangrove

Mangrove. Copyright: 9comeback (Image ID: 141773875).
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Mangroves are trees or large shrubs which grow within the intertidal zone in tropical and subtropical regions and have special adaptations to survive in this environment. Mangrove is in fact a general name for several species of plant which can survive in saline environments. The adaptation has arisen in a number of different families of plants, therefore the general description of mangrove can be applied to a number of different trees, shrubs and even a palm tree and a ground fern. The term mangrove is applied to both the individual plant and the ecosystem, although an area of mangrove habitat is also called *mangal* (Spalding et al. 2010).

Geographic distribution

Mangroves are tropical species generally found on sheltered coastlines and estuaries. They are generally distributed above and below the equator, between the 20°C isotherms. This distribution is locally extended by warm sea currents and decreased by cold ones; mangroves are also sensitive to below zero temperatures and damaged by storms. At colder latitudes, mangroves are often replaced by saltmarsh (Kaiser et al. 2005). Although mangroves are widely distributed in 123 tropical and sub-tropical nations and territories, they are in fact rare at the global scale, covering less than 1% of all tropical forests worldwide (FAO 2006, Spalding et al. 2010, van Lavieren et al. 2012).

Ecology

Mangroves are halophytes: this means that they have evolved mechanisms for salt resistance. There are very few marine ecosystems dominated by plants, but mangroves are one of them. Mangroves provide important foraging grounds and habitats for both marine and terrestrial fauna (Kaiser et al. 2005). Two limiting factors in the distribution of plants generally is the salinity and waterlogged sediment (Kaiser et al. 2005). To cope with the high salinity, mangrove species have a number of mechanisms to remove or exclude salt from their tissues, and certain species have evolved the ability to actively secrete salt from their leaves. The waterlogged, anaerobic soil provides another challenge which has been overcome through the development of aerial roots to transport oxygen to roots which are underground or underwater (Spalding et al. 2010).

Mangroves provide habitats for a vast variety of species. One reason for this is the diversity of habitat structure provided by mangrove, at the boundary between the land and the sea. The tree includes conventional above-ground tree and canopy habitat, and root structures within the soil or sediment, but additional habitat is provided by complex root structures above the soil which are often submerged by seawater. In some cases, these underwater roots support other species such as algae, oysters and sponges which grow on the root surfaces, further increasing the available habitat niches (Kaiser et al. 2005).

As a habitat, mangroves are important for a variety of terrestrial, estuarine and marine species: from sea turtles such as the Critically Endangered hawksbill turtle (*Eretmochelys imbricata*) (Gaos et al. 2012, IUCN 2013), to the Endangered Bengal tiger (*Panthera tigris tigris*) which lives in the Sundarban mangrove ecosystem in India and Bangladesh (Gopal & Chauhan 2006, IUCN 2013). A number of migratory bird species also rely on mangroves as wintering and roosting sites along their migratory routes. For instance, over 50 million migratory shorebirds use the *East Asia-Australian flyway* to migrate from the Arctic Circle through Southeast Asia to Australia and New Zealand, and back. This includes Endangered and Critically Endangered waterbird species, many of which stop to forage at numerous wetlands including mangroves (Kirby et al. 2008, IUCN 2013, Partnership for the East Australian Flyway 2013). Due to their role in supporting endemic, restricted-range and migratory bird species, mangroves are a key habitat at more than 300 Important Bird Areas (IBAs) in the Americas alone (Mangrove Alliance 2013).

Economic & societal value

Mangrove ecosystems provide considerable benefits to surrounding habitats and communities, both locally and at a wider scale. Their proximity to the coastline make them efficient water filters, improving water quality and protecting habitats, such as coral reefs, from siltation, whilst also protecting coastlines from erosion, providing soil stabilisation and storm protection (Murray et al. 2011). Mangroves provide a home and nursery grounds to a rich and complex array of species (Nagelkerken et al. 2002, 2008, Barbier & Hacker 2011). Nursery grounds provide often complex habitats with protective areas out of reach from larger predators, where the juvenile fish grow large enough to then survive in the open waters. Many commercial fish species are known to rely on mangroves as juveniles, and also as adults for their feeding grounds (Aburto-Oropeza et al. 2008).

In terms of economic value, mangroves provide huge benefits. The total economic values for mangrove habitats hence range from US$ 2,772 ha^{-1} yr^{-1} up to as much as US$ 80,334 ha^{-1} yr^{-1} (average US$ 28,662 ha^{-1} yr^{-1}) (Salem & Mercer 2012). The forests are an essential resource for coastal human communities, providing fish, molluscs and crustaceans for trade and consumption and materials such as fuel, timber, honey, medicines and fodder. In a review of values for different types of ecosystem services, the economic values of forestry, fisheries and tourism ranked highly (Salem & Mercer 2012). Storm protection provided by mangroves is also very important, as demonstrated by one case study on storm protection benefits measured in economic terms following a cyclone in India. In villages protected by an embankment without mangroves, the economic losses were over four times greater than in those with mangroves as their sole form of protection (Barbier et al. 2011).

The ability of mangroves to sequester and store huge amounts of carbon plays an important role in global carbon budgets and in the process of mitigating climate change (Herr et al. 2012). Mangroves are recognised as one of the three key 'blue carbon' habitats and are among the most carbon-rich forests in the tropics. They are able to sequester 6 to 8 tonnes of carbon dioxide equivalent per hectare per year (Murray et al. 2011). These rates are about two to four times greater than rates observed in mature tropical forests (Lewis et al. 2009).

Threats

Over the last century, there has been extensive loss and degradation of mangrove habitats due to coastal development, pollution, aquaculture, and logging for timber and fuel wood. As a result, 20% of the total area of mangroves was lost between 1980 and 2005 (Spalding et al. 2010, Crooks et al. 2011) and mangrove habitat continues to decline at an estimated rate of 1-2% annually (FAO 2003). Of the remaining mangrove stands, it is estimated that 52% are degraded due to shrimp/fish culture, 26% due to forest use, and 11% due to freshwater diversion (Valiela et al. 2001). As a result, mangroves and the species that depend on them are at an elevated risk of extinction. At the present rate of loss, the world faces a real risk of losing the services provided by mangroves entirely in the next 100 years (Duke et al. 2007).

International threat status

Of the 70 true mangrove species, three are Endangered, and two Critically Endangered (Polidoro et al. 2010, IUCN 2013). The species that are dependent on mangroves are also at risk. At least 40% of the animal species that are restricted to mangrove habitat are at elevated risk of extinction due to extensive habitat loss (Luther & Greenberg 2009). For example, the pygmy three-toed sloth *(Bradypus pygmaeus)*, endemic to a small island of Panama, feeds primarily on mangrove leaves and is listed as Critically Endangered due to the loss red mangrove forest and their small range (IUCN 2013). The loss of the mangrove habitats also affects the local communities who depend on them, either directly or indirectly.

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Seagrass

Seagrass meadow. Copyright: R. Carey (Image ID: 140959252).
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Seagrasses are a unique group of flowering plants that grow in the shallow coastal waters of most continents (Hartog 1970). Seagrasses can form vast aggregations, or meadows, which alter the flow of water, nutrient cycling and food web structure of the local environment (Hemminga & Duarte 2000).

Geographic distribution

Seagrasses are broadly distributed in most of the world's oceans and seas, including the Black and Caspian Seas. The global distribution of seagrasses extends up within the Arctic Circle, where they are present in northern Russia, Norway and Alaska. Seagrass has also been recorded as far south as New Zealand. Strong wave action, nutrient concentration, ice scouring, depth and water turbidity are some of the limiting factors to the distribution of seagrasses.

Ecology

Seagrasses have evolved the ability to grow completely submerged by seawater, and have an underwater pollination system. They are able to cope with saline water, and have rooting structures which allow them to withstand the movement of water.

Seagrass meadows provide numerous ecological services, acting as essential habitat (e.g. spawning, nursery, refuge and foraging areas) for many animals, including commercially and recreationally important fish species (Watson et al. 1996, de la Torre-Castro & Rönnbäck 2004), whilst providing a major source of food for a range of large herbivores such as the Endangered green sea turtle (*Chelonia mydas*), and Vulnerable dugongs and manatees (Carruthers et al. 2002, IUCN 2013).

Furthermore, the benefits provided by a healthy seagrass meadow extends beyond the local area, through exporting key nutrients (e.g. nitrogen and phosphate) and organic carbon to other parts of the oceans, including some to the deep-sea where they provide a critical supply of organic matter in an extremely food-limited environment (Orth et al. 2006). Much of the excess organic carbon produced is buried within the seagrass sediments, making seagrass habitat an important blue carbon habitat.

Seagrasses are considered to be ecosystem engineers. Ecosystem engineers play key roles in ecosystem organisation by providing conditions or resources essential for species to complete their life cycles, or by helping to maintain niche diversity such as by providing complex habitat structures (Keith et al. 2013). They cover large areas and provide a complex structure which allow them to support thousands of other species (Jackson 2001).

Economic & societal value

Seagrass meadows are one of the three 'blue carbon' habitats because of their carbon storage capability (Nellemann et al. 2009a). In addition to their value as a nursery and refuge for important fish species, seagrass meadows modify currents and waves, and trap and store sediments and nutrients, acting as a filter for coastal waters. They have an economic value attributed to such services estimated at US$ 34,000 ha^{-1} yr^{-1}, a figure greater than many terrestrial and marine habitats (Short et al. 2011). As outlined above, these habitats are of great importance for a range of reasons, and as such are recommended to be included in regional marine conservation priorities, e.g. in the Indo-Pacific (Unsworth & Cullen 2010).

Threats & international threat status

Seagrass habitats help stabilise the marine sediment and provide a framework for the accumulation of more sediment and other materials (Jackson 2001). Seagrasses and the associated ecosystem services they provide are, however, under direct threat from a host of anthropogenic factors. A synthesis of 215 published studies showed that seagrass habitat has disappeared worldwide at a rate of 110 km^2 yr^{-1} between 1980 and 2006 (Short et al. 2011). Of the 72 seagrass species listed in the IUCN Red List of Threatened Species, three are Endangered (Short et al. 2011, IUCN 2013). As seagrasses require some of the highest light levels of any plant group worldwide, the primary threat is loss of water clarity and quality, often brought about by eutrophication and sediment loading stemming from reclamation, shoreline hardening, and dredging within coastal regions (Orth et al. 2006). Additionally, seagrass meadows are threatened by a multitude of environmental factors that are currently changing or will change in the future including rising sea levels, changing tidal regimes, UV radiation damage, sediment oxygen depletion and deprivation, increases in sea temperatures and increases in the occurrence of storm and flooding events (Björk et al. 2008).

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Saltmarsh

Bon Secour National wildlife refuge Alabama. Copyright: D.E. Hooks (Image ID: 55817833). Used under license from Shutterstock.com.

Saltmarshes, also called saltwater marshlands or saline marshes, are ecosystems located in the intertidal zone of sheltered marine and estuarine coastlines. The intertidal zone is the seashore area which is covered by water at high tide but exposed to the air at low tide. Saltmarshes are dominated by salt tolerant grasses, herbs and low shrubs.

Geographic distribution

Saltmarshes tend to grow in areas exposed to relatively low energy waves, such as estuaries and tidal inlets. Saltmarshes develop where fine sediment has accumulated to an appropriate elevation and salt tolerant plants have colonised the surface. The roots of these colonisers help to stabilise the sediments and slow water flow, encouraging further deposition of sediment and stabilising the marsh surface (Adam 2002). Saltmarshes are distributed on coastlines around the world, particularly in temperate and arctic regions. In tropical areas, saltmarshes tend to be replaced by mangroves, which grow in a similar zone of the seashore. The most extensive saltmarshes occur where there are large tidal ranges (Marbef 2013).

Ecology

Saltmarshes are of ecological importance as they underpin the estuarine food web. Saltmarshes serve as nesting, nursery and feeding grounds for numerous species of birds, fish, molluscs and crustaceans, including commercially important fish species such as herring (*Clupea harengus*) (Hughes 2004, Jones et al. 2011). The shallow water and vegetation provides hiding places and abundant food for juvenile fish and various invertebrate species. Larger predators cannot enter these areas, making them a temporary safe haven while the fish have a chance to grow (Segar 2012).

Saltmarshes are also home to a number of Endangered and Critically Endangered species. An example of the unique and rare species found in this habitat includes the endangered saltmarsh harvest mouse (*Reithrodontomys raviventris*) (IUCN 2013), one of the few terrestrial mammals in the world able to drink seawater if fresh is not available (Haines 1964). Saltmarshes are a particularly important breeding, foraging, overwintering and migration stop off points for many waterfowl species (Marbef 2013).

Economic & societal value

Saltmarshes are also significant for human well-being and economies as they provide a range of ecosystem services, such as coastal defence, nutrient cycling, water filtration, immobilisation of pollutants and carbon sequestration (UNEP 2006). Saltmarshes are one of three key coastal 'blue carbon' habitats, recognised for their ability to store carbon within above- and below-ground biomass and sediments (Laffoley & Grimsditch 2009). With an average annual carbon sequestration rate of 6 to 8 tonnes of carbon dioxide equivalent per hectare (Murray et al. 2011), saltmarshes sequester carbon at a rate two to four times greater than that recorded for mature tropical forests (Lewis et al. 2009).

Threats

Saltmarsh habitats are threatened by climate change-induced sea level rise as their capacity to migrate landward is often restricted by infrastructure, embankments or topography, resulting in loss due to "coastal squeeze" (Hughes 2004). Habitat loss is also driven by local-scale anthropogenic activities, such as drainage for agriculture and mosquito control, development of coastal infrastructure and ports, coastal ecosystem eutrophication, conversion to salt ponds, and infill for coastal development (UNEP 2006, Deegan et al. 2012).

International threat status

Despite providing essential ecosystem services, saltmarshes have not traditionally been a habitat of high priority for conservation and have lost between 25% and 50% of their global historical coverage (Nellemann et al. 2009b, Crooks et al. 2011). The rate of loss is currently around 1-2% per year (Duarte et al. 2008).

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Sea turtle nesting site

Baby loggerhead sea turtle on beach. Copyright: B. Albiach Galan.
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Sea turtles are air-breathing reptiles spending most of their lives at sea. All sea turtle species lay their eggs on land, typically on sandy beaches. Sea turtles may migrate hundreds or even thousands of kilometres between established feeding and breeding sites (Plotkin 2003, Hays et al. 2004, Limpus et al. 2009).

Geographic distribution

The seven different species of sea turtles occupy different, although often overlapping, geographic ranges. In general, sea turtles occupy a wide range of oceanic habitats and will travel widely in their lifetimes. The leatherback turtle (*Dermochelys coriacea*) is global in distribution, with the exception of the poles (Hawkes et al. 2009, Segar 2012). Turtles are reptiles, so they use the external environment to moderate their temperature. For this reason, temperature generally provides some level of restriction to their movements, and most species prefer sea temperatures above 20°C (Lutz et al. 2003). The leatherback turtle is more tolerant to lower temperatures and has been sighted as far North as the waters of Newfoundland, in temperatures ranging from 0 to 15°C (Milton & Lutz 2003).

Sea turtle nesting beaches are much more restricted in their geographic distribution, with the major nesting areas for most species being located in the tropical and subtropical regions (Sternberg 1981). Turtles are also able to migrate between their foraging and nesting sites with a high degree of accuracy, with many displaying a strong degree of nest site fidelity (Miller 1997, Heppell et al. 2003)

Ecology

During the breeding/nesting seasons, both sexes typically aggregate in the waters close to the nesting beaches (Hamann et al. 2003, Bonin et al. 2006). Kemp's ridley and olive ridley turtles can exhibit mass nesting events (or 'Arribada'), during which thousands of females come up to nest at the same time on the same beaches (Miller 1997, Valverde et al. 2012), possibly to lower predation risk (although there are advantages and disadvantages to both 'Arribada' and 'solitary' nesting; Bernardo & Plotkin 2007).

Sea turtles provide a key ecological component when abundant. They are part of the marine food web, within which they are both prey and consumer. They are also important in substrate and nutrient transport, helping to ensure a healthy functioning system (Bjorndal & Bolten 2003).

Economic & societal value

Turtles have been hunted throughout their history of interactions with human populations. In the early days of shipping, sea turtles were caught and kept on the decks of ships where they stayed alive for weeks, providing a fresh source of meat for the sailors. Turtles are still caught for food, and their eggs are a delicacy in some regions (Senko et al. 2011). Turtle shell from hawksbill turtles is made into jewellery and other ornamental pieces. Oil and leather are other products sourced from sea turtles. Unfortunately, this direct consumption is leading to population declines in many species.

Turtle tourism has provided more sustainable source of economic revenue in some regions (Wilson & Tisdell 2003). Turtles are a charismatic marine species and hold fascination for people who see them.

Threats

Fisheries bycatch is regarded as the main threat to sea turtles globally (Wallace et al. 2013). As slow-growing species, with relatively late sexual maturity (between 7 and 30 years, depending on the species; Heppell et al. 2003), they are particularly vulnerable to the impacts of bycatch (Žydelis et al. 2008) and the degradation of breeding and nesting habitats. It is hence essential that nesting sites are preserved, both in quality and surface area.

Nesting beaches themselves are under threat from a variety of factors. Human exploitation of eggs and hunting of nesting females is a significant threat in many areas (Campbell 2003, Shanker 2004 and references therein). The development of coastal areas is linked with increased pollution, water quality degradation, erosion and overexploitation of natural resources (Lotze et al. 2006). Noise and light pollution can disturb nesting females and disorientate emerging hatchlings on their way to the sea, and vehicle use can cause compaction and destroy nests (Witherington 1997, Demetropoulos 2000). Feral pigs and dogs cause significant nesting losses in some areas (Márquez-M & Márquez-M. 2004), and litter may prevent hatchling movement and cause deleterious effects to adult turtles (Ramos et al. 2012).

In addition to direct impacts, the temperature-sensitive sex determination and migratory behaviour of sea turtles make them particularly vulnerable to the impacts of climate change (Poloczanska et al.

2009). Increased nesting beach temperatures have been shown to skew the sex ratio of hatchlings with increased percentage of females being born in warmer nest sites (Hawkes et al. 2009). Finally, sea level rise is recognised as a significant threat to turtle nesting sites(Limpus 2006), with a 0.5 m rise in sea level predicted to result in a loss of up to 32% of the total current beach area of a Caribbean island, with lower, narrower beaches being the most vulnerable (Fish et al. 2005).

International threat status

Of the seven existing species of sea turtles, three are classified as Critically Endangered (hawksbill turtle *Eretmochelys imbricata*, Kemp's ridley turtle *Lepidochelys kempii* and leatherback turtle *Dermochelys coriacea*), two as Endangered (green turtle *Chelonia mydas* and loggerhead turtle *Caretta caretta*), one as Vulnerable (olive ridley turtle *Lepidochelys olivacea*), and one as Data Deficient (flatback turtle *Natator depressus*) (IUCN 2013). The range of global threat levels indicates varying population dynamics across species, but also masks disparate population trends across different regions of the world (Godfrey & Godley 2008, Seminoff & Shanker 2008). For instance, the Marine Turtle Specialist Group of the IUCN highlighted steep declines in the populations of leatherback turtles and loggerhead turtles in the Pacific (Mast et al. 2006), but encouraging trends were recorded in Kemp’s ridley turtles (Tamaulipas and Vera Cruz, Mexico), and small but steady nesting populations of hawksbill turtles (Buck Island, Caribbean) (Heppell et al. 2003).

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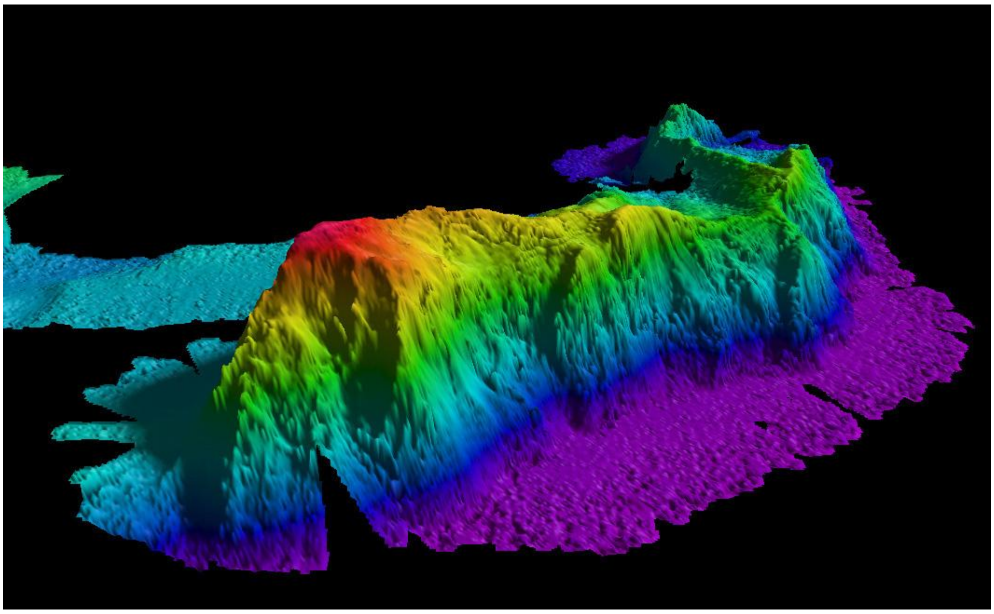
Seamount



Seamount map created using a multibeam echo sounder (Arctic Ocean).
Credit: NOAA[31].

Seamounts, or undersea mountains, are widespread and prominent topographical features of volcanic origin that rise up to heights of 1,000 m or more from the ocean floor (Rogers 1994). The total number of seamounts remains unknown, but current estimates suggest numbers from 30,000 to 100,000 seamounts globally (Wessel 2001, Yesson et al. 2012).

Geographic distribution

Seamounts are global in distribution. Satellite-derived information has been used to map them because of the effect they have on seawater height above and around them. Rock is denser than water and exerts a gravitational pull on the sea around it, making 'mounds' above the undersea mountain which are then measurable by satellite (Segar 2012). Other mapping efforts have involved bathymetric surveys, numerical modelling and vessel track sounding data collection (Consalvey et al. 2010).

Ecological Description

Found in all oceans, seamounts can be associated with increased biological productivity, due to the upwelling of nutrients caused by currents and eddies near the surface of the structure (Rogers 2004). Moreover, their volcanic substrate can provide appropriate conditions for the development of epifaunal communities of sponges and cold-water corals (Rogers 1994), which together attract many open ocean and deep-sea species of fish, sharks, turtles, marine mammals and seabirds (Rogers 2004, Morato et al. 2010). However, it should be recognised that seamounts vary substantially in

[31] Source: http://www.flickr.com/photos/usoceangov/5369581627/

terms of their physical structure (Rogers 2004) and their associated biological communities, particularly given their different sizes, summit depths, and distance from coastlines.

There has been considerable debate in the scientific literature about the level of endemism and biodiversity associated with seamounts (de Forges et al. 2000, McClain 2007, Rowden et al. 2010). Following a six year programme of study as part of the Census of Marine Life[32], the evidence collected suggested that, while seamounts do not always support high levels of endemism, they are potential hotspots of species richness and they support distinct communities.

Economic & societal value

The study of seamounts has provided fascinating insights into tectonic plates and the movement in geological time of magma hotspots under the crust (Segar 2012). In ecological terms, there is evidence that suggests that seamounts are hotspots of pelagic biodiversity in the open ocean, and have higher catch rates of some highly migratory species from longline fisheries, including Vulnerable species such as the shark shortfin mako (*Isurus oxyrinchus*) and the billfish blue marlin (*Makaira nigricans*) (Morato et al. 2010, IUCN 2013). Fishing vessels are often active around seamounts because of the higher catch volumes associated with them, despite the risk of these becoming unsustainable in the long term (see threats section).

Seamounts may also provide refuge from habitat disruption due to climate change, specifically for the effects of ocean acidification (Tittensor, Baco, et al. 2010). Their unique and isolated locations could give them a useful role as refuges from catastrophic environmental events and as stepping stone habitats for dispersal (Rowden et al. 2010).

Threats

Seamounts are known to be at elevated risk of fishing disturbance from bottom trawling (Rowden et al. 2010). Fish often aggregate at seamounts, thereby facilitating high catch volumes. However, the fisheries based around these areas often target deep sea species, which are slow-growing, have low reproductive volumes and are long-lived (some individual fish have been aged at over 100 years old). Fish populations targeted around seamount are hence comparatively more vulnerable to overfishing. More widely, marine biological communities associated with seamounts are considered among the least resilient to disturbance (Clark et al. 2010).

Another threat to seamounts may come from mining and extractive activities and carbon sequestration[33]. Although these activities are currently at the exploration stages, their effects would need to be carefully monitored and managed to avoid or minimise long term impacts. Effects of disturbance could be physical, such as the creation of sediment plumes. In addition and because of the isolation of seamount communities, there is the possibility of causing the extinction of unique fauna through damaging only one location. These impacts are similar to that of fishing, and there is merit in management of both these potential threats (Clark et al. 2010).

[32] www.coml.org
[33] The process of capture and long-term storage of atmospheric carbon dioxide.

International threat status

There has been no international assessment of the risk that seamount habitats are under. The considerable gaps in knowledge on these areas, because of the difficulty and expense of carrying out research in such an extreme environment, make it currently impossible to quantify the risks. However, it is clear that some fish species of commercial importance and which are found on seamounts are declining (Clark 2001) and that following disturbance events, the recovery of fauna and habitat-forming species such as corals and sponges is slow or absent, making them very fragile systems (Clark et al. 2010).

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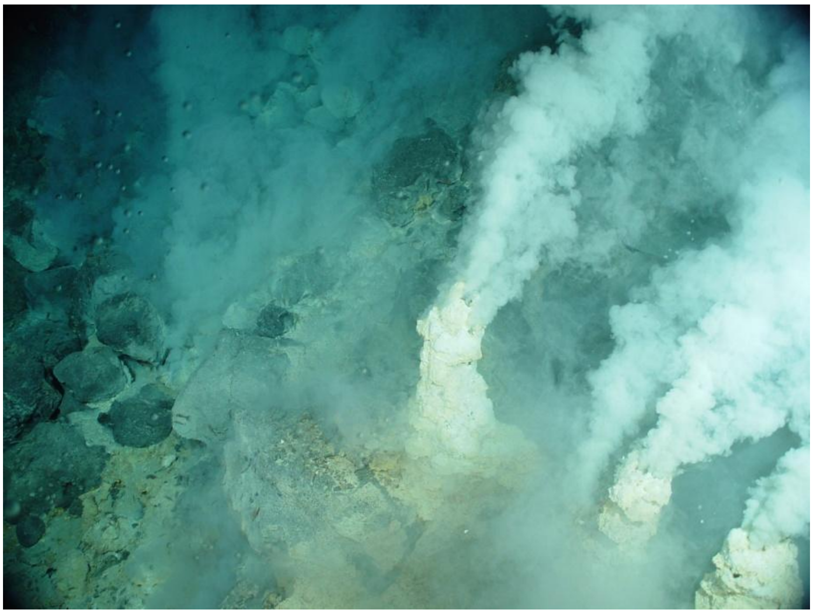
Hydrothermal vent



White chimneys at Champagne vent site, NW Eifuku volcano (Western Pacific Ocean).
Credit: NOAA and Dr. Bob Embley[34].

First discovered in 1977, deep-sea hydrothermal vents are typically small-scale sites that emit geothermally heated water. Hydrothermal vents form as a result of volcanic activity below the ocean floor. Sea water, which permeates into the seafloor, is heated by this geothermal activity. The water, rich with dissolved metals and minerals, erupts out of the sea-floor from the vents which often look like chimneys with coloured 'smoke' erupting from them. 'Black smokers' are the hottest type of vent where the plumes of water can reach temperatures of 400°C (Baker et al. 2010). Fauna, which live around these vents, are based on chemosynthetic food chains where the species at the lower end of the food chain, typically bacteria, synthesise energy from the chemicals in the water. Chemosynthesis is the equivalent to photosynthesis, but organisms produce energy from chemicals (e.g. sulphur) instead of sunlight.

Geographic distribution

Hydrothermal vents are globally distributed, but their location is determined by tectonic conditions. Where plates form, such as mid-oceanic ridges and in areas where there is volcanic activity, the Earth's magma is close to the seafloor and can heat water which has seeped down. The hydrothermal vents are therefore associated with regions of high tectonic activity and intersections of continental plates (Kaiser et al. 2005).

Ecology

Hydrothermal vent areas can support very densely populated ecosystems, where faunal density and biomass are comparatively greater than the surrounding seafloor (Baker et al. 2010). In addition,

[34] Source: http://www.flickr.com/photos/noaaphotolib/5014973927/

hydrothermal vents also support highly unique fauna: this unique fauna includes chemosynthetic microbes (bacteria and archaea), that in turn supports evolutionary and ecologically unique communities of shrimps, crabs, tube worms, clams, and other species that exist in no other habitat on Earth (Van Dover 2000). Within and around vents, researchers have discovered 500+ new animal species, over 80% of which are endemic to vents (Van Dover 2000). This high rate of endemism is a likely result of the unusual physiological adaptations necessary for survival in such an extreme environment, meaning that these species are highly evolutionary distinct (e.g. chemosynthetic organisms dependent on the sulphur produced) (Beatty et al. 2005). In addition, a very high proportion of species are likely to be extremely rare, often comprising only a few recorded observations of individuals (Baker et al. 2010).

Observations of deep-sea vent ecosystems and their flora and fauna over recent decades have stimulated new theories on the origin and evolution of life on Earth, lending even greater weight to the importance of these extremely spatially-restricted ecosystems (Martin et al. 2008). Marine protected areas have been established at deep-sea hydrothermal fields, notably in Canadian and Portuguese waters (UNEP-WCMC 2008), and their representation within protected areas is likely to increase further over coming years (Van Dover et al. 2012).

Economic & societal value

The scientific advances that discoveries at hydrothermal vents have allowed have considerable value. Hydrothermal vents revealed a totally new domain of chemistry on the Earth. Hypothesis on the origin of life on Earth immediately changed because the vent environments provided examples of new types of chemically reactive environments which could mirror what existed at the dawn of time. These systems have also provided insights into the limits of life in extreme conditions, for example a living organism was found replicating at 121°C, currently thought to be the upper temperature limit to life (Martin et al. 2008). Hydrothermal vents are an important focus for research because of their unique nature and potential to significantly advance scientific understanding (InterRidge 2001).

Vent sites are being considered for their potential to support valuable mineral deposits. The activity of the vent results in potentially commercially valuable resources and a number of companies are already showing interest in exploiting these resources through bioprospecting (McIntyre 2010, Wedding et al. 2013). At present, the future usefulness of these potential resources remains to be quantified, but the value of organisms that function in extreme environments has been estimated to be $ 500 million per year for bacteria collected from hot springs, thereby highlighting the possible benefits (InterRidge 2001).

Threats

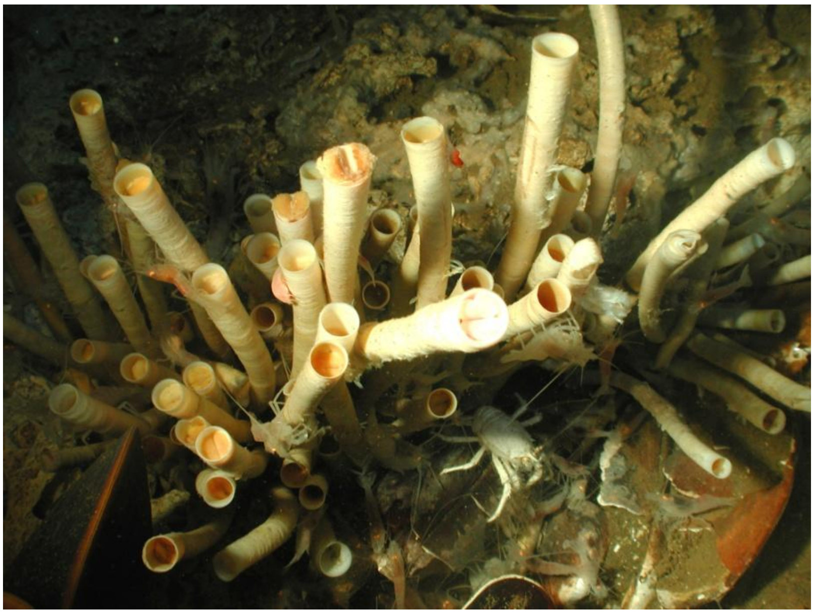
Hydrothermal vent ecosystems are new to science and have had limited scrutiny because of the difficulty and expense in getting to them. Because the chemosynthetic communities are so new and unstudied, there is a risk that threats such as deep sea fishing could impact on species and habitats before they are known to science (Baco et al. 2010). Of the potential threats to these habitats, mining is considered to be one that could cause considerable damage. Seafloor Massive Sulphide (SMS) deposits are of great interest because they potentially contain significant quantities of commercially valuable metals such as gold (Baker et al. 2010). At this stage, there are very few businesses involved in this domain, and the activity is at very early stage exploration. Types of threats include direct damage to the seafloor and vent structure, which could potentially lead to the extinction of species, and production of sediment plumes, which could smother filter-feeding organisms. Impacts, such as noise and alteration of the fluid dynamics, are also a concern.

International threat status

There has been no international assessment of the risk that hydrothermal vent habitats are under. The considerable gaps in knowledge about these areas, because of the difficulty and expense of studying in such an extreme environment, make it currently impossible to quantify the risks.

Last updated: February 2014

Cold Seep



A cold seep community of tube worms, squat lobster, white shrimp, and mussel shells. The tubeworms mine for sulfide in the carbonate substrate with their roots.
Credit: Lophelia II 2010 Expedition, NOAA-OER/BOEMRE[35].

Cold seep ecosystems are found where sulphur and methane emerge from seafloor sediments without an appreciable temperature rise (Levin 2005). Also known as cold vents, seeps form by a variety of processes related to over-pressuring (e.g. of sediments, or from mineral dehydration reactions and gas hydrate dynamics) (Tunnicliffe et al. 2003). These environments, and the communities associated with them, are among the most recently discovered marine habitats: the first system was found in 1983 on the Florida escarpment in the Gulf of Mexico (Paull *et al.* 1984).

Geographic distribution

Since the first discovery in 1983, active seeps have been reported from all oceans of the world, the highest number occurring within active subduction zones in the Pacific Ocean, along the margins of Alaska, Oregon, California, Central America, Peru, Japan and New Zealand (Levin 2005). Seeps occur most frequently near ocean margins, from intertidal to hadal (6,000+ m) depths. Due to the financial and technological challenges of carrying out research in deep-sea regions, our knowledge of the systems and the species found there has remained relatively poor. For instance, of the 500 putative species described from hydrothermal vent and cold seep environments, not a single one has had its complete life cycle described (Tyler & Young 1999).

Ecology

The habitat created by seeps is linked to the chemicals (e.g. sulphide) they release. These chemicals support a number of chemosynthetic species. Chemosynthesis is the equivalent to photosynthesis,

[35] Source: http://www.flickr.com/photos/noaaphotolib/5277874738/

but organisms produce energy from chemicals (e.g. sulphur) instead of sunlight. Chemosynthetic species range from single-celled organisms (e.g. bacteria) that live in the surrounding sediment and utilise the methane produced (Orphan *et al.* 2002), to communities of large invertebrate taxa including clams, mussels or worms. Populations of these larger more complex invertebrates are sustained thanks to symbiotic[36] bacteria that carry out chemosynthesis (Levin 2005).

Despite the relatively high biomass found within cold seep areas, species diversity is frequently low (Levin 2005, Vanreusel et al. 2010, Seitzinger et al. 2010). This is the result of relatively few species having evolved the physiological and morphological adaptations required to survive in such a challenging environment (Hourdez & Lallier 2006). Consequently, a large proportion of species found in cold seep ecosystems are endemic to them (Sibuet & Olu 1998), with a large number of species found at present at only one geographical site (Bergquist et al. 2003). These unique systems have also helped fuel new theories on the origin of life (Martin *et al.* 2008).

Economic & societal value

Organisms which are found in extreme environments are often of commercial interest because of their unique adaptations. In the marine environment, bioprospecting is looking to the deep sea's extreme environments, including cold seeps, for novel organisms with pharmaceutical potential (Synnes 2006).

Threats

Cold seep ecosystems are new to science and hence have had limited scrutiny because of the difficulty and expense in getting to them. Of the potential threats to these habitats, mining is considered to be one which could cause considerable damage. Seafloor Massive Sulphide (SMS) deposits are of great interest because they potentially contain significant quantities of commercially valuable metals such as gold (Baker et al. 2010). At this stage, there are very few businesses involved in this domain, and the activity is at very early stage exploration. Types of threats include direct damage to the seafloor and seep structure, which could potentially lead to the extinction of species, and production of sediment plumes, which could smother filter feeding organisms. Other impacts such as noise and alteration of the fluid dynamics are a concern. The oil and gas industry could also potentially impact this habitat: indeed, this industry is likely to be active in these areas because seep communities can coincide with hydrocarbon reservoirs and gas hydrates (Baker et al. 2010).

An industry which has been found to already be causing damage is the fishing industry. Evidence of impact from deep water trawling has been recorded at a number of cold seep sites around the globe. In Chile, the commercially exploited (and at risk) Patagonian toothfish (*Dissostichus eleginoides*) is associated with cold seep sites (Baker et al. 2010). Because these chemosynthetic communities are so recently discovered and relatively unstudied, there is a risk that deep sea fishing activities could impact on species and habitats before they are known to science (Baco et al. 2010).

[36] Symbiosis is the relationship between two different species of organisms that are interdependent.

International threat status

There has been no international assessment of the risk that cold seep habitats are under. The considerable lack of knowledge makes it almost impossible to quantify the risks.

Last updated: February 2014

Vulnerable Marine Ecosystem

Marine ecosystems which are easily damaged because of their physical and functional fragility

Fishing trawler. Copyright: papa1266 (Image ID: 76959202).
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Supported by: Food and Agriculture Organization of the United Nations (FAO)
Spatial coverage: global in extent
Year of creation: 2008

In 2006, the UN General Assembly invited the Food and Agriculture Organization of the United Nations (FAO) to consider creating a global database of information on Vulnerable Marine Ecosystems (VME) in marine Areas Beyond National Jurisdiction (ABNJ), to assist States in assessing any impacts of bottom fisheries on these benthic ecosystems. Paragraph 90 of the resolution invited States and Regional Fisheries Management Organizations or Arrangements (RFMO/As) to submit information to the database on all VMEs identified (United Nations General Assembly 2007).

In August 2008, the *International Guidelines for the Management of Deep-sea Fisheries in the High Seas*, developed through FAO (FAO 2009), were adopted by FAO Members at a Technical Consultation in Rome, where they defined detailed criteria for identifying VMEs. The main objective of these *Guidelines* is to focus on the sustainable management of deep sea fisheries, so as to promote responsible fisheries that provide economic opportunities, while ensuring the conservation of marine living resources and the protection of marine biodiversity (FAO 2009). The *Guidelines* are a voluntary tool through which to achieve this objective of better managed fisheries and protected VMEs.

Description

Deep-sea fisheries commonly target species which may be particularly sensitive to exploitation because they exhibit life history traits such as slow growth, low reproductive output and long life expectancy (FAO 2009). Deep sea ecosystems more generally present these traits and may hence be particularly vulnerable to the impacts of fishing gear. In response to the threats faced by these habitats, the United Nations General Assembly (UNGA) took a Resolution requesting that RFMO/As and States regulate deep-sea bottom fisheries and address significant adverse impacts on VMEs (United Nations General Assembly 2007).

Vulnerability as defined in the *Guidelines* (FAO 2009) is "related to the likelihood that a population, community, or habitat will experience substantial alteration from short-term or chronic disturbance, and to the likelihood that it would recover and in what time frame" (FAO 2009). Under European law, VMEs are defined as "any marine ecosystem whose integrity (i.e. ecosystem structure or function) is, according to the best scientific information available and to the precautionary principle, threatened by significant adverse impacts resulting from physical contact with bottom gears in the normal course of fishing operations, including, *inter alia*, reefs, seamounts, hydrothermal vents, cold water corals or cold water sponge beds. The most vulnerable ecosystems are those that are easily disturbed and in addition are very slow to recover, or may never recover" (Council of the European Union 2008).

Detailed criteria for the identification of VMEs can be found in Paragraph 42 of the *Guidelines* (FAO 2009). There is considerable overlap in criteria between VMEs and Ecologically or Biologically Significant Areas (EBSAs), which are identified through the Convention on Biological Diversity (CBD; 1992). However, the VME criteria differ in having an internationally agreed process for their identification and a management response (UNEP 2010). VMEs are applied primarily as a management response to issues in deep-sea fisheries and are often embedded in the management process of RFMOs. In contrast and as the name infers, EBSAs are used to identify areas of biological or ecological importance, which are not directly associated with threats, a specific zone of the oceans or a specific management systems.

FAO is currently in the process of building a 'VME database' to facilitate information exchange on these sensitive ecosystems. The potential users of the database are those wishing to access information on the work that is, and that has been, undertaken by RFMOs on VMEs in marine ABNJ. This database includes information on specific VMEs, Regional Fisheries Bodies (or State), management measures, and management and scientific meeting reports that are connected with VMEs and that are often widely dispersed through various documents that are difficult and time consuming to locate.

Criteria

A marine ecosystem should be classified as vulnerable based on the characteristics that it possesses (FAO 2009):

"(i) *Uniqueness or rarity* – an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems. These include:

- habitats that contain endemic species;
- habitats of rare, threatened or endangered species that occur only in discrete areas; or
- nurseries or discrete feeding, breeding, or spawning areas.

(ii) *Functional significance of the habitat* – discrete areas or habitats that are necessary for the survival, function, spawning/reproduction or recovery of fish stocks, particular life-history stages (e.g. nursery grounds or rearing areas), or of rare, threatened or endangered marine species.

(iii) *Fragility* – an ecosystem that is highly susceptible to degradation by anthropogenic activities.

(iv) *Life-history traits of component species that make recovery difficult* – ecosystems that are characterised by populations or assemblages of species with one or more of the following characteristics:

- slow growth rates;
- late age of maturity;
- low or unpredictable recruitment; or
- long-lived.

(v) *Structural complexity* – an ecosystem that is characterised by complex physical structures created by significant concentrations of biotic and abiotic features. In these ecosystems, ecological processes are usually highly dependent on these structured systems. Further, such ecosystems often have high diversity, which is dependent on the structuring organisms."

Examples of potentially vulnerable species groups, communities and habitats, as well as features that potentially support them are listed in an annex to the *Guidelines* (FAO 2009) and include cold-water corals, sponges, as well as biological communities associated with seamounts, cold seeps and hydrothermal vents. The criteria can be adapted and additional criteria may be developed as experience and knowledge accumulate, or to address particular local or regional needs (FAO 2009). A ten-step framework was recently published, aiming at providing guidelines on the process to follow from initial identification through to the protection of VMEs (Ardron et al. 2013).

Management

Management and conservation steps are included in the *Guidelines* (FAO 2009) under the following headings:

- data, reporting and assessment;
- identifying VMEs and assessing significant adverse impacts;
- enforcement and compliance; management and conservation tools; and
- assessment and review of effectiveness of measures.

The *Guidelines* apply to “fisheries that occur in areas beyond the limits of national jurisdiction” (FAO 2009), specifically deep sea fisheries where (i) the total catch (everything brought up by the gear) includes species that can only sustain low exploitation rates; and (ii) the fishing gear is likely to make contact with the seafloor during the normal course of fishing operations.

Business relevance

Legislation and policy

The output from Rio +20 was entitled *The Future We Want* (United Nations 2012). It made a commitment to enhance actions to protect VMEs, including through the effective use of impact assessments.

A number of resolutions from the United Nations General Assembly (UNGA) highlight the importance of addressing the adverse impacts of bottom fishing and to consider the long-term sustainability of deep sea fish stocks (e.g. Resolutions 61/105, 64/72 and 66/68) (United Nations General Assembly 2013). These Resolutions call for the sustainable management of bottom fisheries.

In relation to ABNJ, the United Nations Convention on Law of the Sea (UNCLOS; 1982) provides that the high seas are open to all States, under the regime of the freedom of the high seas, including freedom to lay submarine cables and pipelines and freedom of fishing. Flag States have hence exclusive jurisdiction over vessels flying their flag on the high seas. The *Guidance* (FAO 2009) is a voluntary instrument, which is provided to States as a reference for formulating and implementing appropriate measures for the management of deep-sea fisheries in the high seas. The FAO considers their adoption as a major step forward in addressing both fisheries management and marine biodiversity conservation in an integrated manner, and contributes to the development and strengthening of the applicable legal and institutional framework (FAO 2013).

In Europe, legislation has been enacted to support the sustainable management of deep sea fisheries (Council of the European Union 2008)

Biodiversity

The marine benthic environment is extremely biodiverse. It has been estimated that approximately 98% of known marine species live in benthic environments and that more species live in benthic environments than in all other environments on Earth combined (United Nations General Assembly 2004). The United Nations General Assembly has identified a number of habitats which could be considered vulnerable ecosystem features, such as those found in coastal areas (i.e. warm-water coral reefs, wetlands, seagrass beds, coastal lagoons, mangroves and estuaries). Also included are those found in areas within and beyond national jurisdiction, such as spawning and nursery grounds, cold-water corals, seamounts, various features associated with polar regions, hydrothermal vents, deep-sea trenches and submarine canyons, and oceanic ridges (United Nations General Assembly 2004).

Social and cultural values

The value of VMEs to society is through the services that they provide. Given the location of some of these features in the deep sea, they are not a visible element of the natural environment except through nature documentary film-making. Filming deep sea habitats is indeed becoming popular, with technological advances allowing access to these areas. Fisheries also bring the animals of the deep sea to people's tables worldwide. There are also considerable possibilities for bio-prospecting (i.e. seabed mining for minerals) in some of these areas (Wedding et al. 2013), and they possibly hold potentially valuable marine genetic resources. For example sponges, which are often found on seamounts, have in the past been a source of medically active compounds (Cragg & Newman 2005).

Last updated: April 2014

Annex 2. Dataset summary table

Coloured shading in the table below are used to indicate that:

- the dataset can be viewed and/or downloaded from UNEP-WCMC's *Ocean Data Viewer*[37] and related *Data Download*[38] page,
- more information about dataset access can be sought directly from UNEP-WCMC[39].

For all other datasets, information about data layer access can be found in the metadata (if available) or should be sought from the named contact organisation. **UNEP-WCMC does not distribute these datasets.**

Category	Dataset title	Contact organisation	ID[40]	Metadata	Data access	Factsheet
Biogenic habitat	Global Distribution of Coral Reefs (2010)	UNEP World Conservation Monitoring Centre	WCMC-008	✓	Ocean Data Viewer	p. 30
	Global Distribution of Coral Reefs - 1 Km Data (2003)	UNEP World Conservation Monitoring Centre	WCMC-009	✓	Ocean Data Viewer	p. 30
	Global Distribution of Cold-water Corals (2005)	UNEP World Conservation Monitoring Centre	WCMC-001	✓	Ocean Data Viewer	p. 33
	Global Distributions of Habitat Suitability for Framework-Forming Cold-Water Corals (2011)	School of Ocean Sciences, University of Bangor	Bangor-001			p. 33
	Global Distribution of Habitat Suitability for Stony Corals on Seamounts (2009)	UNEP World Conservation Monitoring Centre	WCMC-024			p. 33
	Global Distributions of Habitat Suitability for Cold-Water Octocorals (2012)	Institute of Zoology, Zoological Society of London	ZSL-001	✓	See metadata	p. 33
	Modelled Mediterranean Coralligenous	Hellenic Centre for Marine Research	Mediseh-	✓	See metadata	

[37] http://data.unep-wcmc.org (20 datasets for viewing, of which 15 can be downloaded). For commercial use of these datasets, please contact business-support@unep-wcmc.org.
[38] http://datadownload.unep-wcmc.org/datasets (2 datasets for downloading). For commercial use of these datasets, please contact business-support@unep-wcmc.org.
[39] For non-commercial use, please contact marine@unep-wcmc.org; for commercial use, contact business-support@unep-wcmc.org.
[40] Internal UNEP-WCMC numbering system as part of our metadata cataloguing.

Category	Dataset title	Contact organisation	ID[40]	Metadata	Data access	Factsheet
	and Mäerl Distributions (2013)		001			
	Global Distribution of Mangroves USGS (2011)	UNEP World Conservation Monitoring Centre	WCMC-010	✓	Ocean Data Viewer	p. 35
	World Atlas of Mangroves (2010)	UNEP World Conservation Monitoring Centre	WCMC-011	✓	Ocean Data Viewer	p. 35
	Global Distribution of Mangroves (1997)	UNEP World Conservation Monitoring Centre	WCMC-012	✓	Ocean Data Viewer	p. 35
	Global Distribution of Seagrasses (2005)	UNEP World Conservation Monitoring Centre	WCMC-013-014	✓	Ocean Data Viewer	p. 39
	Modelled *Posidonia oceanica* Distribution in the Mediterranean Sea (2013)	Tor Vergata University	Mediseh-002	✓	See metadata	p. 39
	Global Distribution of Saltmarsh (2013)	UNEP World Conservation Monitoring Centre	WCMC-027	✓	See metadata	p. 41
Species habitat	Global Distribution of Marine Turtle Nesting Sites (1999)	UNEP World Conservation Monitoring Centre	WCMC-007	✓	Data Download Page	p. 43
	Global Distribution of Marine Turtle Nesting Sites (2011)	State of the World's Sea Turtles	SWOT-001			p. 43
	Global Distributions of Habitat Suitability for Marine Turtle Nesting Sites (2012)	State of the World's Sea Turtles	SWOT-002			p. 43
	Global Distribution of Marine Turtle Feeding Sites (1999)	UNEP World Conservation Monitoring Centre	WCMC-006	✓	Data Download Page	
Species distribution	Spatial Data for the Red List of Threatened Species (2013)	International Union for Conservation of Nature	IUCN-001			
	Global Register of Migratory Species (2004)	Zoologisches Forschungsinstitut und Museum Alexander Koenig	GROMS-001			
	Global Distribution of Marine Turtles (2010)	State of the World's Sea Turtles	SWOT-003			
	AquaMaps: Predicted Range Maps for Aquatic Species (2013)	Aquamaps	AquaMaps-001			
	Global Distribution of Northern Fur Seals (2013)	Albert-Ludwigs-University of Freiburg	Kaschner-001	✓	See metadata	
	Global Distribution of Hawaiian Monk Seals (2013)	Albert-Ludwigs-University of Freiburg	Kaschner-002	✓	See metadata	
	Global Distribution of Grey Seals (2013)	Albert-Ludwigs-University of Freiburg	Kaschner-	✓	See metadata	

Category	Dataset title	Contact organisation	ID[40]	Metadata	Data access	Factsheet
			003			
	Global Distribution of Hector's Dolphins (2013)	Albert-Ludwigs-University of Freiburg	Kaschner-004	✓	See metadata	
	Global Distribution of Northern Bottlenose Whales (2013)	Albert-Ludwigs-University of Freiburg	Kaschner-005	✓	See metadata	
	Global Distribution of Sperm Whales (2013)	Albert-Ludwigs-University of Freiburg	Kaschner-006	✓	See metadata	
	Global Distribution of Bowhead Whales (2013)	Albert-Ludwigs-University of Freiburg	Kaschner-008	✓	See metadata	
	Global Distribution of Sei Whales (2013)	Albert-Ludwigs-University of Freiburg	Kaschner-009	✓	See metadata	
	Global Distribution of Atlantic Spotted Dolphins (2013)	Albert-Ludwigs-University of Freiburg	Kaschner-011	✓	See metadata	
	Global Distribution of Melon-Headed Whales (2013)	Albert-Ludwigs-University of Freiburg	Kaschner-012	✓	See metadata	
	Marine Species Datasets of the World's Oceans (2013)	Ocean Biogeographic Information System, Intergovernmental Oceanographic Commission (UNESCO)	OBIS-003			
	Global Shark Distribution Database (2009)	Dalhousie University	UniDalh-002			
	Marine Animal Tracking (2013)	Ocean Tracking Network, Dalhousie University	UniDalh-001			
	Tagging of Pacific Predators in the Pacific Ocean (2013)	Tagging of Pacific Predators	TOPP-001			
Biodiversity metric	Global Patterns of Marine Biodiversity (2010)	UNEP World Conservation Monitoring Centre	WCMC-019	✓	Ocean Data Viewer	
	Global Map of Shannon's Index of Biodiversity (2014)	Ocean Biogeographic Information System, Intergovernmental Oceanographic Commission (UNESCO)	OBIS-001	✓	Ocean Data Viewer	
	Global Map of Hurlbert's Index of Biodiversity (2014)	Ocean Biogeographic Information System, Intergovernmental Oceanographic Commission (UNESCO)	OBIS-002	✓	Ocean Data Viewer	
	Global Seagrass Species Richness (2003)	UNEP World Conservation Monitoring Centre	WCMC-015	✓	Ocean Data Viewer	
	Global Marine Turtle Species Richness (2002)	UNEP World Conservation Monitoring Centre	WCMC-003		Contact UNEP-WCMC	

Category	Dataset title	Contact organisation	ID[40]	Metadata	Data access	Factsheet
Area of biodiversity importance	World Database on Protected Areas (2013)	UNEP World Conservation Monitoring Centre	WCMC-016	✓	See metadata	
	Global Distribution of KBAs, IBAs and AZEs (2013)	Birdlife International	Birdlife-001	✓	See metadata	
	Ecologically or Biologically Significant Areas in the Mediterranean Sea (2010)	Regional Activity Centre for Specially Protected Areas, UNEP Mediterranean Action Plan	RAC-SPA-001	✓	See metadata	
	Global Distribution of Vulnerable Marine Ecosystems (*expected 2014*)	Food and Agriculture Organization of the United Nations	FAO-002			p. 55
	Global Distribution of Particularly Sensitive Sea Areas (2012)	International Maritime Organization	IMO-001			
	Areas of Particular Environmental Interest (2012)	International Seabed Authority	ISA-001			
	A Global Map of Critical Habitat (2013) as per IFC PS6	UNEP World Conservation Monitoring Centre	WCMC-029		Contact UNEP-WCMC	
Biogeographic classification	Marine Ecoregions of the World (2007)	UNEP World Conservation Monitoring Centre	WCMC-017	✓	Ocean Data Viewer	
	Pelagic Provinces of the World (2012)	UNEP World Conservation Monitoring Centre	WCMC-018	✓	Ocean Data Viewer	
	A Proposed Biogeography of the Deep Oceans (2013)	University of Hawaii	UniHaw-001			
	Large Marine Ecosystems of the World (2002)	National Oceanic and Atmospheric Administration	NOAA-001			
	Longhurst Biogeographical Provinces (2006)	Flanders Marine Institute	VLIZ-002			
	The Global 200 Ecoregions (2002)	World Wildlife Fund	WWF-001			
	Geomorphology of the oceans (2014)	GRID-Arendal, Geoscience Australia, Conservation International	BlueHab-001			
	Global Distribution of Seamounts and Knolls (2011)	Institute of Zoology, Zoological Society of London	ZSL-002	✓	See metadata	p. 46
	Global Seamount Database (2011)	School of Ocean and Earth Science and Technology, University of Hawaii	UniHaw-003			p. 46
	SeamountsOnline: an Online Information System for Seamount Biology (2009)	San Diego Supercomputer Center, University of California	UniCal-001			p. 46
	Global Distribution of Hydrothermal Vents (2010)	University of Southampton, National Oceanography Centre	ChEssBase-002	✓	See metadata	p. 49

Category	Dataset title	Contact organisation	ID[40]	Metadata	Data access	Factsheet
	Global Distribution of Hydrothermal Vent Fields (2013)	InterRidge, Peking University	IntRid-001	✓	See metadata	p. 49
	Global Distribution of Cold Seeps (2010)	University of Southampton, National Oceanography Centre	ChEssBase-001	✓	See metadata	p. 51
Ecological status and impact	A Global Map of Human Impacts to Marine Ecosystems (2008)	National Centre for Ecological Analysis and Synthesis, University of California	NCEAS-001			
	Global Data for the Ocean Health Index (2012)	National Centre for Ecological Analysis and Synthesis, University of California	NCEAS-002			
	SeagrassNet: Global Seagrass Monitoring Network (2013)	Washington State Department of Natural Resources, Aquatic Resources Division	WaDNR-001	✓	See metadata	
	Coral Disease Database (2009)	UNEP World Conservation Monitoring Centre	WCMC-004		Contact UNEP-WCMC	
	Global Distribution of Dive Centres (2001)	UNEP World Conservation Monitoring Centre	WCMC-030		Contact UNEP-WCMC	
Environment descriptor	General Bathymetric Chart of the Oceans (2008)	British Oceanographic Data Centre	GEBCO-001			
	Bio-ORACLE: a Global Environmental Dataset for Marine Species Distribution Modelling (2012)	Phycology Research Group, Ghent University	Ghent-001			
	Mean Sea Surface Productivity in June and December 2003-2007 (2008)	UNEP World Conservation Monitoring Centre	WCMC-020-021	✓	Ocean Data Viewer	
	Mean Annual Sea Surface Temperature 2003-2007 (2008)	UNEP World Conservation Monitoring Centre	WCMC-022	✓	Ocean Data Viewer	
Administration	Global Self-consistent, Hierarchical, High-resolution Geography Database (2013)	School of Ocean and Earth Science and Technology, University of Hawaii	UniHaw-001	✓	See metadata	
	Global Maritime Boundaries Database (2008)	General Dynamics Advanced Information Systems, Inc.	GMBD-001			
	Global Distribution of Islands (2010)	UNEP World Conservation Monitoring Centre	WCMC-005	✓	See metadata	
	Exclusive Economic Zone boundaries (2012)	Flanders Marine Institute	VLIZ-001	✓	See metadata	
	Regional Seas Boundaries (unofficial)	UNEP World Conservation Monitoring Centre	UNEP-002	✓	See metadata	
	Boundaries of the Global International Waters Assessment (2003)	Division of Early Warning and Assessment, United Nations Environment Programme	UNEP-001	✓	See metadata	
	Global Distribution of Regional Fishery Bodies (2010)	Food and Agriculture Organization of the United Nations	FAO-001	✓	See metadata	

Category	Dataset title	Contact organisation	ID[40]	Metadata	Data access	Factsheet
	Global Distribution of Ports: World Port Index (2011)	National Geospatial - Intelligence Agency	NG-AI-001			

Annex 3. Detailed dataset-specific metadata

This annex (distributed separately and previewed in Figure 1) compiles the metadata sheets available to date for 45 datasets. Page numbers within annex 3 are given overleaf.

The metadata format is based on the metadata database used by the British Geological Survey to meet international spatial metadata standards such as the European INSPIRE Directive or ISO 19115[41].

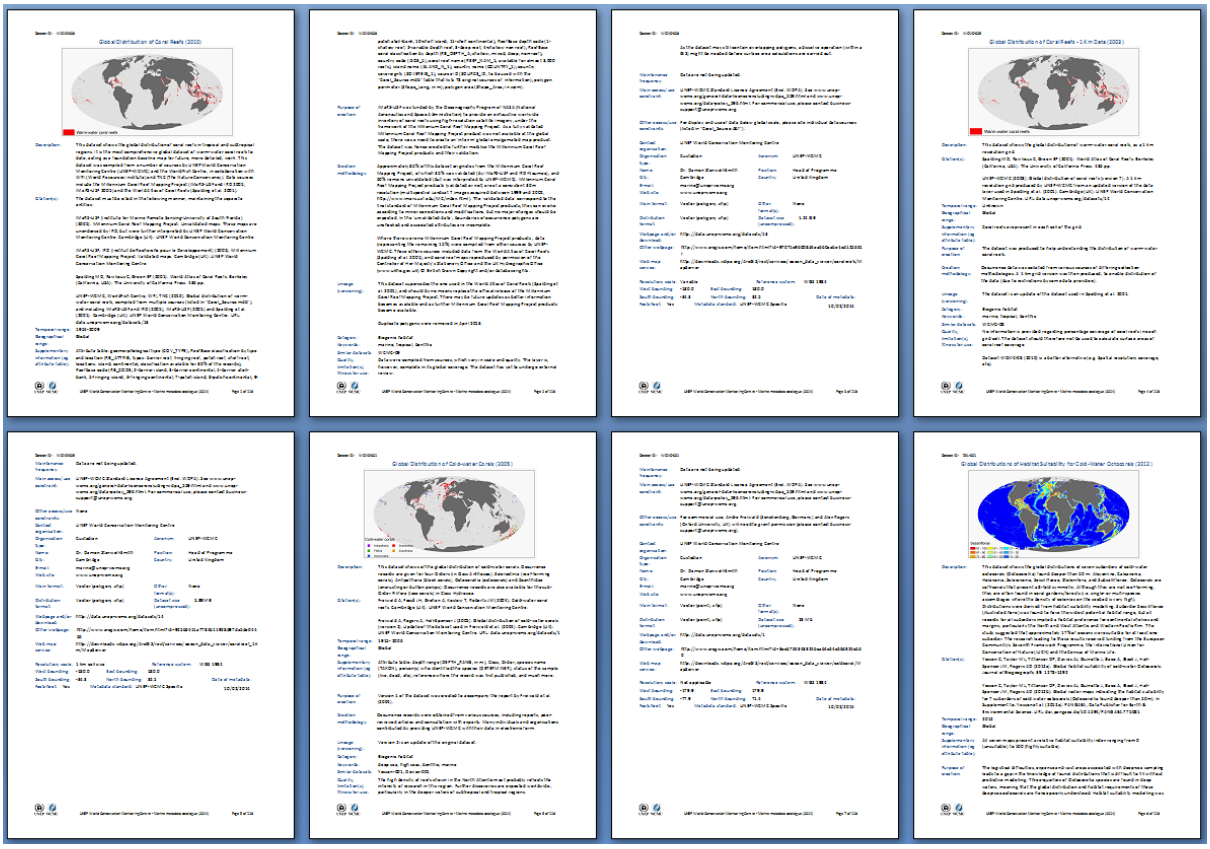

Figure 1. Preview of the separately-distributed annex 3 (118 pp.), which compiles all the dataset-specific metadata sheets available to date.

[41] For further details, see http://www.bgs.ac.uk/downloads/start.cfm?id=2880.

Dataset title	ID[42]	Annex 3
Global Distribution of Coral Reefs (2010)	WCMC-008	p. 1
Global Distribution of Coral Reefs - 1 Km Data (2003)	WCMC-009	p. 4
Global Distribution of Cold-water Corals (2005)	WCMC-001	p. 6
Global Distributions of Habitat Suitability for Cold-Water Octocorals (2012)	ZSL-001	p. 8
Modelled Mediterranean Coralligenous and Mäerl Distributions (2013)	Mediseh-001	p. 11
Global Distribution of Mangroves USGS (2011)	WCMC-010	p. 14
World Atlas of Mangroves (2010)	WCMC-011	p. 17
Global Distribution of Mangroves (1997)	WCMC-012	p. 20
Global Distribution of Seagrasses (2005)	WCMC-013-014	p. 22
Modelled *Posidonia oceanica* Distribution in the Mediterranean Sea (2013)	Mediseh-002	p. 25
Global Distribution of Saltmarsh (2013)	WCMC-027	p. 28
Global Distribution of Marine Turtle Nesting Sites (1999)	WCMC-007	p. 30
Global Distribution of Marine Turtle Feeding Sites (1999)	WCMC-006	p. 32
Global Distribution of Northern Fur Seals (2013)	Kaschner-001	p. 34
Global Distribution of Hawaiian Monk Seals (2013)	Kaschner-002	p. 37
Global Distribution of Grey Seals (2013)	Kaschner-003	p. 40
Global Distribution of Hector's Dolphins (2013)	Kaschner-004	p. 43
Global Distribution of Northern Bottlenose Whales (2013)	Kaschner-005	p. 46
Global Distribution of Sperm Whales (2013)	Kaschner-006	p. 49
Global Distribution of Bowhead Whales (2013)	Kaschner-008	p. 52
Global Distribution of Sei Whales (2013)	Kaschner-009	p. 55
Global Distribution of Atlantic Spotted Dolphins (2013)	Kaschner-011	p. 58
Global Distribution of Melon-Headed Whales (2013)	Kaschner-012	p. 61
Global Patterns of Marine Biodiversity (2010)	WCMC-019	p. 64
Global Map of Shannon's Index of Biodiversity (2014)	OBIS-001	p. 67
Global Map of Hurlbert's Index of Biodiversity (2014)	OBIS-002	p. 69
Global Seagrass Species Richness (2003)	WCMC-015	p. 71
World Database on Protected Areas (2013)	WCMC-016	p. 73
Global Distribution of KBAs, IBAs and AZEs (2013)	Birdlife-001	p. 76
Ecologically or Biologically Significant Areas in the Mediterranean Sea (2010)	RAC-SPA-001	p. 79
Marine Ecoregions of the World (2007)	WCMC-017	p. 81
Pelagic Provinces of the World (2012)	WCMC-018	p. 84
Global Distribution of Seamounts and Knolls (2011)	ZSL-002	p. 87
Global Distribution of Hydrothermal Vents (2010)	ChEssBase-002	p. 90
Global Distribution of Hydrothermal Vent Fields (2013)	IntRid-001	p. 93
Global Distribution of Cold Seeps (2010)	ChEssBase-001	p. 95
SeagrassNet: Global Seagrass Monitoring Network (2013)	WaDNR-001	p. 98
Mean Sea Surface Productivity in June and December 2003-2007 (2008)	WCMC-020-021	p. 100
Mean Annual Sea Surface Temperature 2003-2007 (2008)	WCMC-022	p. 102
Global Self-consistent, Hierarchical, High-resolution Geography Database (2013)	UniHaw-001	p. 104
Global Distribution of Islands (2010)	WCMC-005	p. 107
Exclusive Economic Zone boundaries (2012)	VLIZ-001	p. 109
Regional Seas Boundaries (unofficial)	UNEP-002	p. 112
Boundaries of the Global International Waters Assessment (2003)	UNEP-001	p. 114
Global Distribution of Regional Fishery Bodies (2010)	FAO-001	p. 116

[42] Internal UNEP-WCMC numbering system as part of our metadata cataloguing.

Annex 4. Marine mammal maps (K. Kaschner/AquaMaps)

Introduction

The information presented in this annex is the result of a collaboration between UNEP-WCMC and marine mammal expert Dr. Kristin Kaschner (Aquamaps; Albert-Ludwigs-University of Freiburg, Germany). Through this collaboration, modelled data layers on the spatial distributions of three pinnipeds and seven cetaceans (Table 1) were prepared. These species were selected so as to produce a representative sample of the following:

- range of IUCN conservation statuses (IUCN 2012),
- quality of predictions using the AquaMaps modelling approach,
- availability of independent datasets for comparison with the AquaMaps predictions,
- size of spatial distributions.

Table 1. Marine mammal species for which spatial data layers were obtained from Dr. Kristin Kaschner. The conservation status is according to IUCN (2013): CR – critically endangered; EN – endangered; VU – vulnerable; LC – least concern; DD – data deficient). *: Atlantic stock is CR. The availability of metadata (compiled in annex 3) is indicated (✓).

Group	Common name	Scientific name	IUCN status	Spatial data	Metadata
Pinniped	Northern fur seal	*Callorhinus ursinus*	VU	Annual map	✓
	Hawaiian monk seal	*Monachus schauinslandi*	CR	Annual map	✓
	Grey seal	*Halichoerus grypus*	LC	Annual map	✓
Cetacean	Hector's dolphin	*Cephalorhynchus hectori*	EN	Annual map	✓
	Northern bottlenose whale	*Hyperoodon ampullatus*	DD	Annual map	✓
	Sperm whale	*Physeter macrocephalus*	VU	Annual map	✓
	Bowhead whale	*Balaena mysticetus*	LC*	Annual map	✓
	Sei whale	*Balaenoptera borealis*	EN	Annual map	✓
	Atlantic spotted dolphin	*Stenella frontalis*	DD	Annual map	✓
	Melon-headed whale	*Peponocephala electra*	LC	Annual map	✓

The general idea behind this collaboration was to go beyond traditional expert-derived range maps, such as those provided by the IUCN[43] (IUCN 2013). Such manually- or expert-delineated maps depict the whole range of individual species, without highlighting where the species in question is more or less likely to be found. These types of range maps are often fairly subjective and delineation may vary between different experts. Furthermore, the underlying rationale for selecting boundaries is generally not transparent and hence difficult to reproduce.

In the present piece of work, a numerical model was used to produce outputs based on a clearly defined set of assumptions, and a transparent approach utilising as input (i) available occurrence

[43] 2013 Red List Spatial Data; http://www.iucnredlist.org/technical-documents/spatial-data.

data and (ii) information about species habitat usages (including expert-knowledge). In addition to delineating reproducible range extents, these predictions also provided information on the relative probability of occurrence of selected marine mammal species, throughout their respective ranges. From the numerical model outputs, the known and probable global distributions were derived. The maps were then expert-reviewed and validated to the extent possible.

The AquaMaps approach (general methodology)

Aquamaps (Kaschner et al. 2014) is an online species distribution model that allows the generation of standardised digital range maps of aquatic species, currently covering more than 17,000 species. Maps are generated using a modified version of the Relative Environmental Suitability (RES) model developed by Kaschner et al. (2006) that uses available information about habitat usage of a given species, projected into geographic space, to help visualise its distribution. Habitat usage is quantitatively described with the help of so-called environmental envelopes defining a species' preference with respect to a set of pre-defined environmental conditions, including:

- depth,
- sea-ice concentration,
- temperature,
- salinity, and
- primary production.

By default, envelopes are derived from occurrence records available through the Global Biodiversity Information Facility[44] (GBIF) supplemented by additional information obtained through online species databases such as FishBase[45] and SeaLifeBase[46]. Acknowledging the sampling biases of currently available online occurrence data, however, AquaMaps explicitly also allows for experts to review and modify environmental envelopes manually.

Map outputs represent annual average predictions of the maximum range extent of species (defined as the maximum area between the known outer-most limits of a species' regular or periodic occurrence) and gradients of relative habitat suitability or species occurrences (ranging from 0 to 1), predicted for each 0.5 degree latitude by 0.5 degree longitude cells. Predictions represent a visualisation of the basic environmental niche of a species, which may often be closer to the historic occurrence of species or its potential niche rather than its realised or currently occupied niche. Binary range maps corresponding more closely to areas of known occurrence may be derived using presence thresholds ideally defined by validation analysis (Kaschner et al. 2011) (see below).

AquaMaps predictions for different species have been validated using independent datasets (Kaschner et al. 2006, 2011, Ready et al. 2010) and generally capture existing knowledge of large-scale and long-term annual average species occurrence reasonably well. However, given the overall paucity of data and the frequently large sampling biases in the marine environment, produced

[44] GBIF (www.gbif.org)
[45] www.fishbase.org
[46] www.sealifebase.org

outputs should be regarded as hypotheses of species occurrence, based on a clearly defined set of documented and transparent assumptions that can be tested and further refined as new data become available. Moreover, since marine mammal habitat usage often varies across seasons and ocean basins, global predictions should not be used without further review to describe regional species occurrence (and should ideally be checked against independent data) and the overall limitations of data availability, model biases and assumptions, etc, should be kept in mind when using produced outputs for management purposes.

Specific methodology for generating updated annual average maps

Expert-review was based on environmental envelopes computed from the most recent AquaMaps harvest of occurrence data from GBIF in August 2013. For each species, point occurrence records and resulting 0.5 degree presence cells were reviewed to exclude false records (species misidentifications, fossil records and outliers) based on a comparison of published information about species distributions including, but not limited to, IUCN individual species pages (IUCN 2013). Calculated envelopes based on the final subset were further reviewed to ensure that these matched available information about habitat usages as published in the literature. Predictions about the relative probability of occurrence /habitat suitability were then generated based on these reviewed envelopes. Finally, the resulting predictions were reviewed by comparing them with existing information about the maximum range extent and relative occurrence of species within that range, highlighting both false predicted presences and absences.

Quality of predictions is reflected in the assigned rank (1 = worst to 5 = best[47]) associated with all outputs. It should be noted that the top two ranks are only assigned if predictions have been successfully and quantitatively validated using independent effort-corrected survey data throughout the whole range (“5”) or for at least part of the species range (“4”) and as the time available for this project was insufficient for conducting these types of validation, the top rank assigned was a “3” (with the exception of sperm whales for which a quantitative validation had been carried out using data from Antarctic waters).

Presence threshold to be used for producing binary[48] range maps

Validation analyses have shown strong correlations between observed relative species occurrence and predicted relative environmental suitability as predicted by RES[49] and AquaMaps for the majority of species and areas with enough data from large-scale, long-term dedicated marine mammal surveys to allow testing (Kaschner et al. 2006, 2011, Ready et al. 2010). Observed species densities tend to be highest in areas of predicted relative probability > 0.4 to 0.6, and validation analysis indicated that this is the most likely presence threshold that should be used to produce the most likely representation of known and probable occurrence of the species, although this may vary

[47] http://www.aquamaps.org/rating.html
[48] i.e. presence/absence.
[49] Relative Environmental Suitability.

for different species[50]. The threshold recommended in the individual species files are based on a precautionary approach that should be used in light of existing uncertainties and in the context of environmental impact assessment.

Mapped predictions

Figures 1 to 10 show the modelled distribution maps for all ten species considered here.

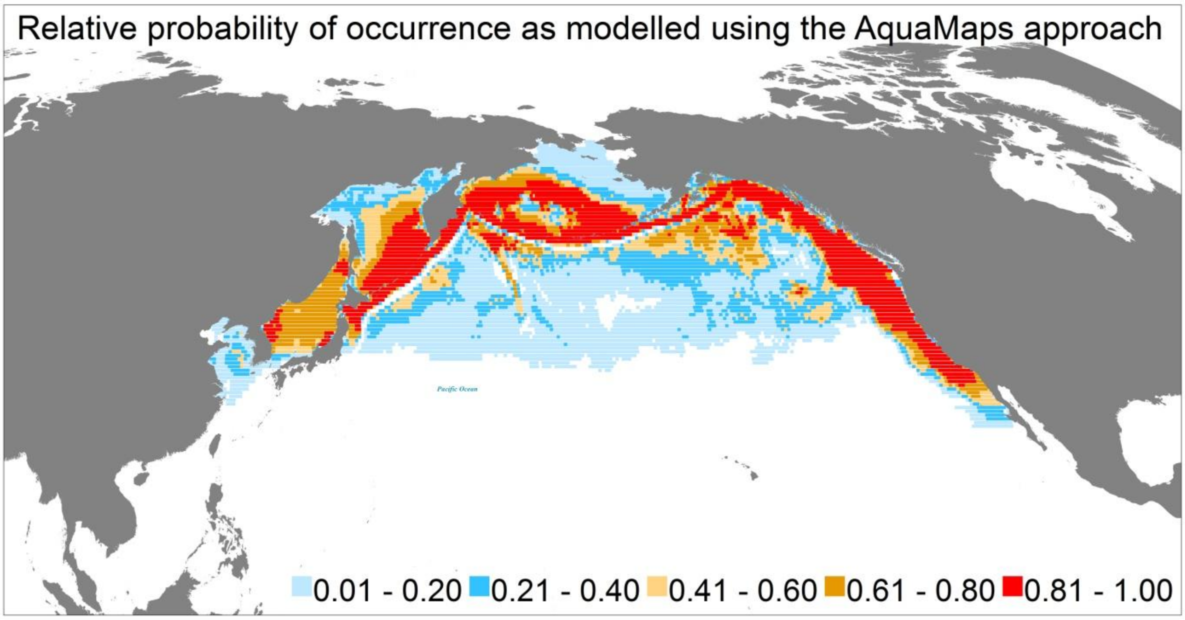

Figure 1. Modelled distribution map for the northern fur seal.

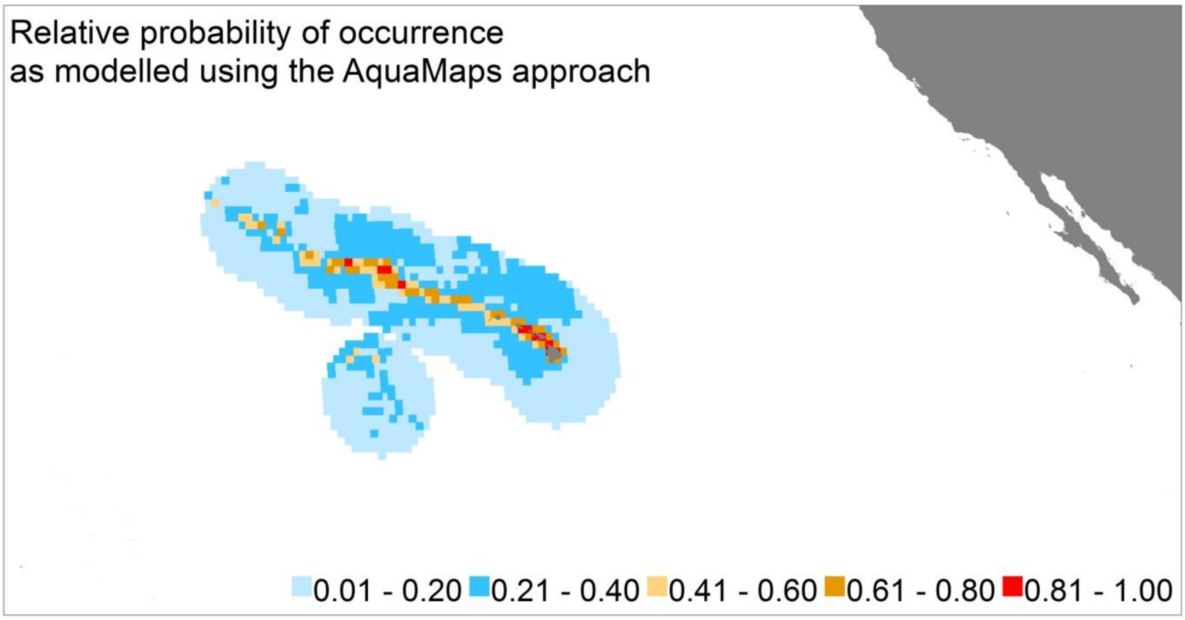

Figure 2. Modelled distribution map for the Hawaiian monk seal.

[50] Please refer to dataset-specific metadata.

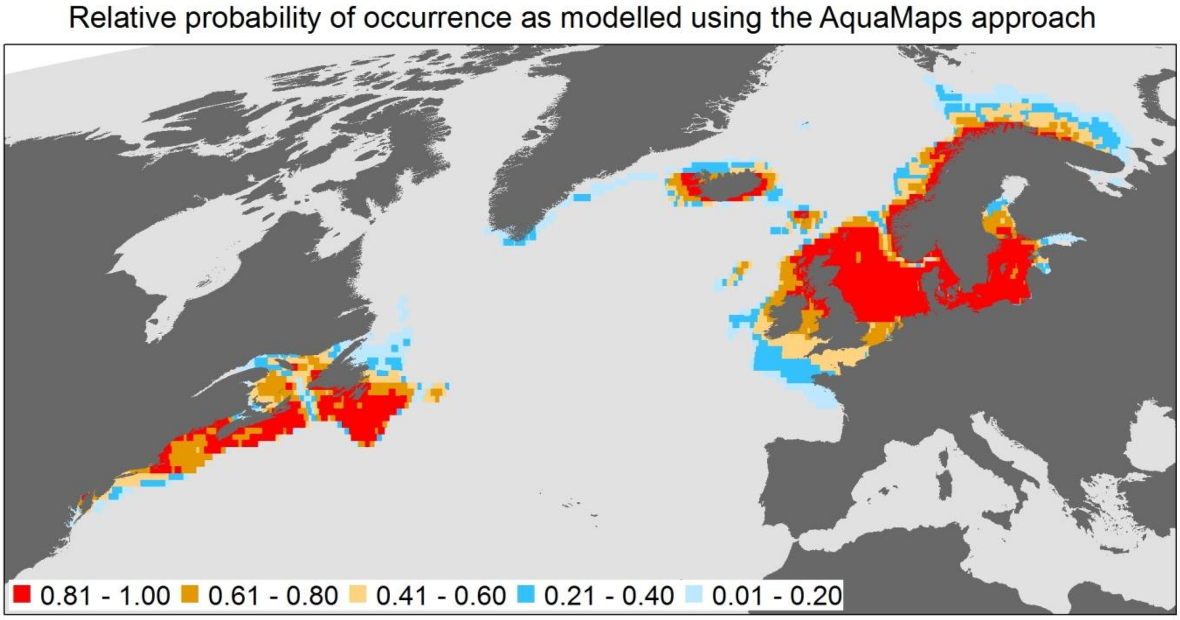

Figure 3. Modelled distribution map for the grey seal.

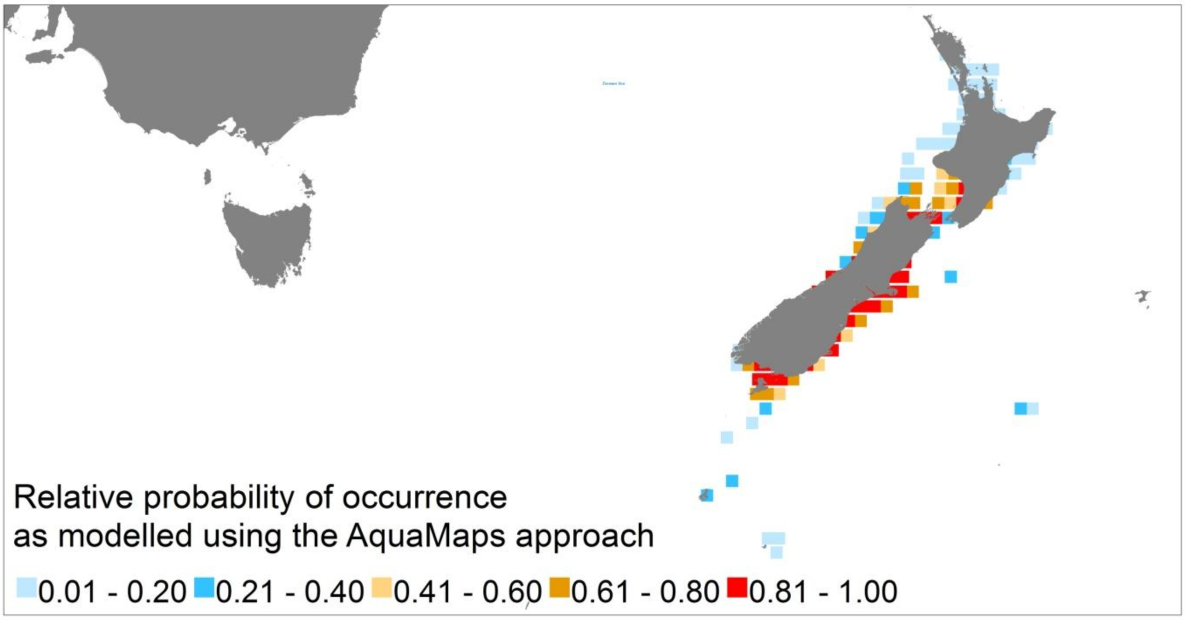

Figure 4. Modelled distribution map for Hector's dolphin.

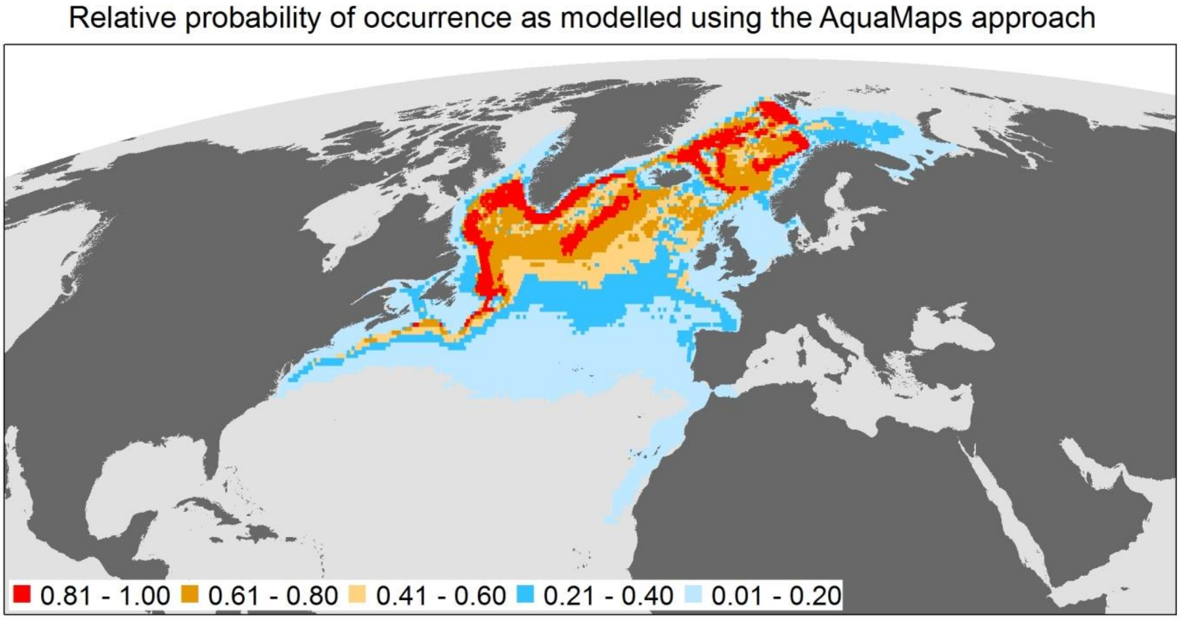

Figure 5. Modelled distribution map for the northern bottlenose whale.

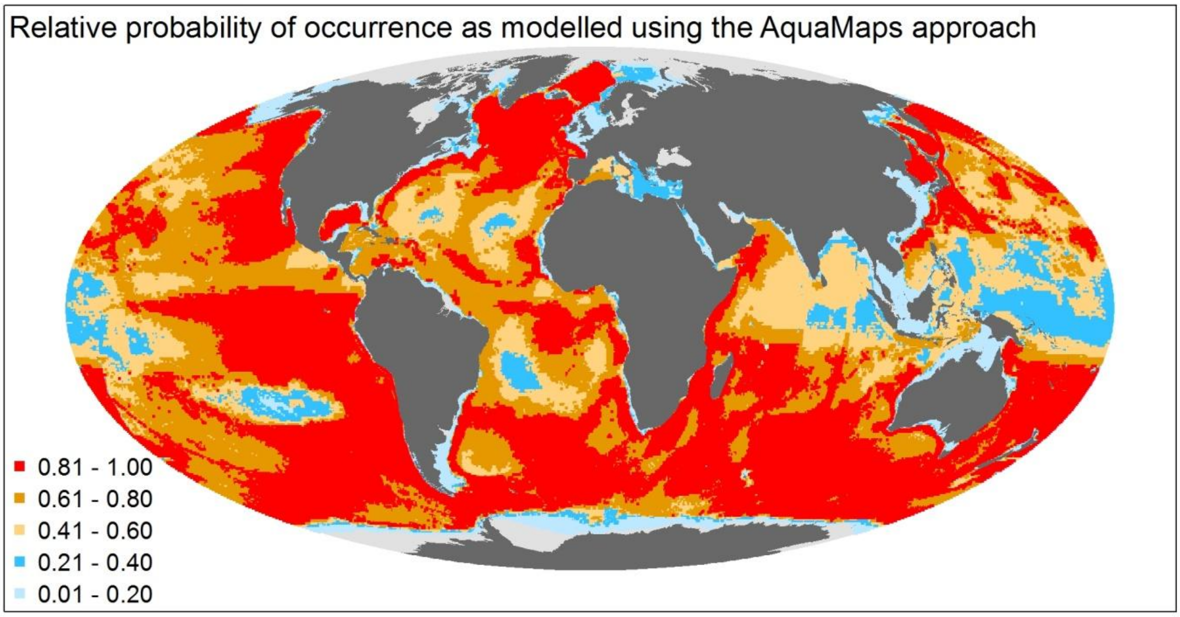

Figure 6. Modelled distribution map for the sperm whale.

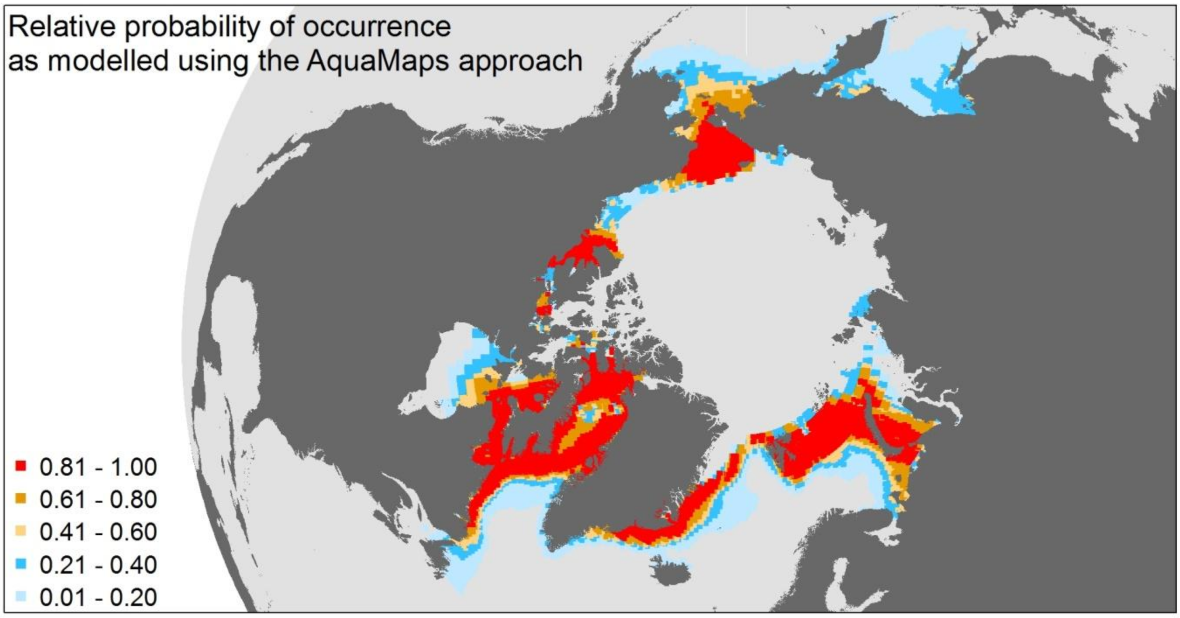

Figure 7. Modelled distribution map for the bowhead whale.

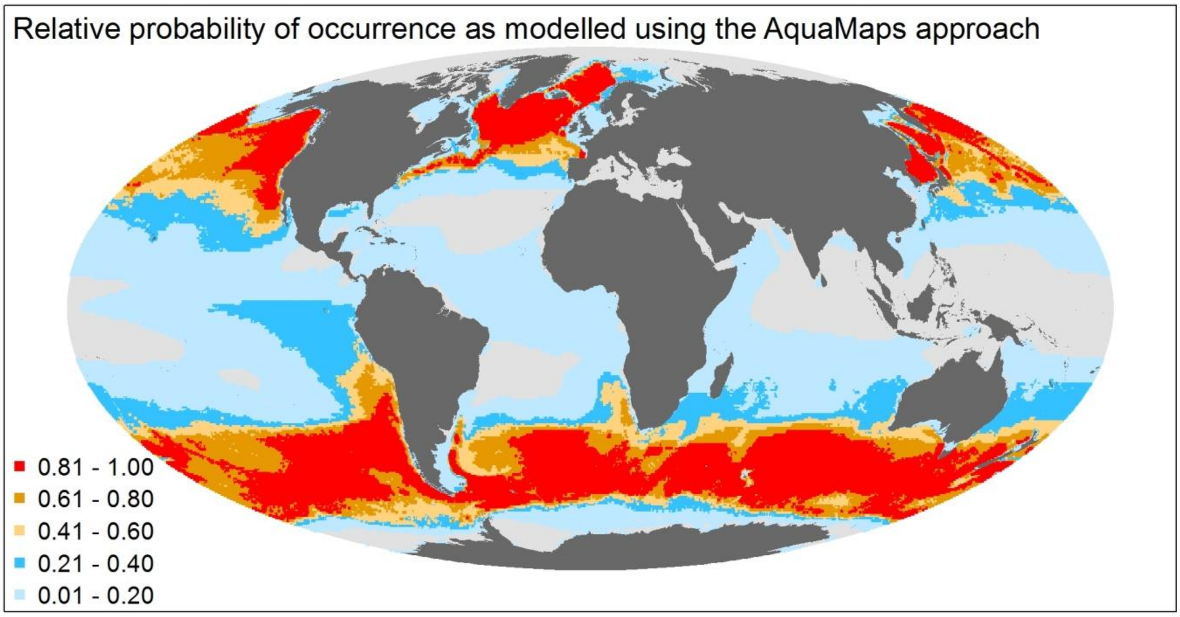

Figure 8. Modelled distribution map for the sei whale.

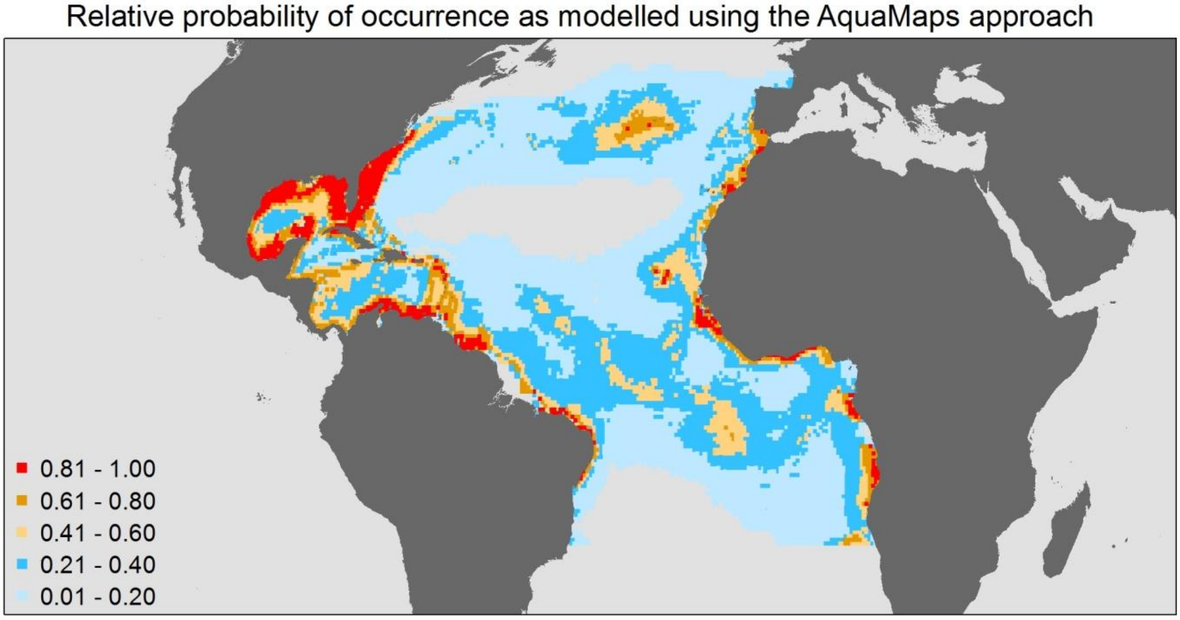

Figure 9. Modelled distribution map for the Atlantic spotted dolphin.

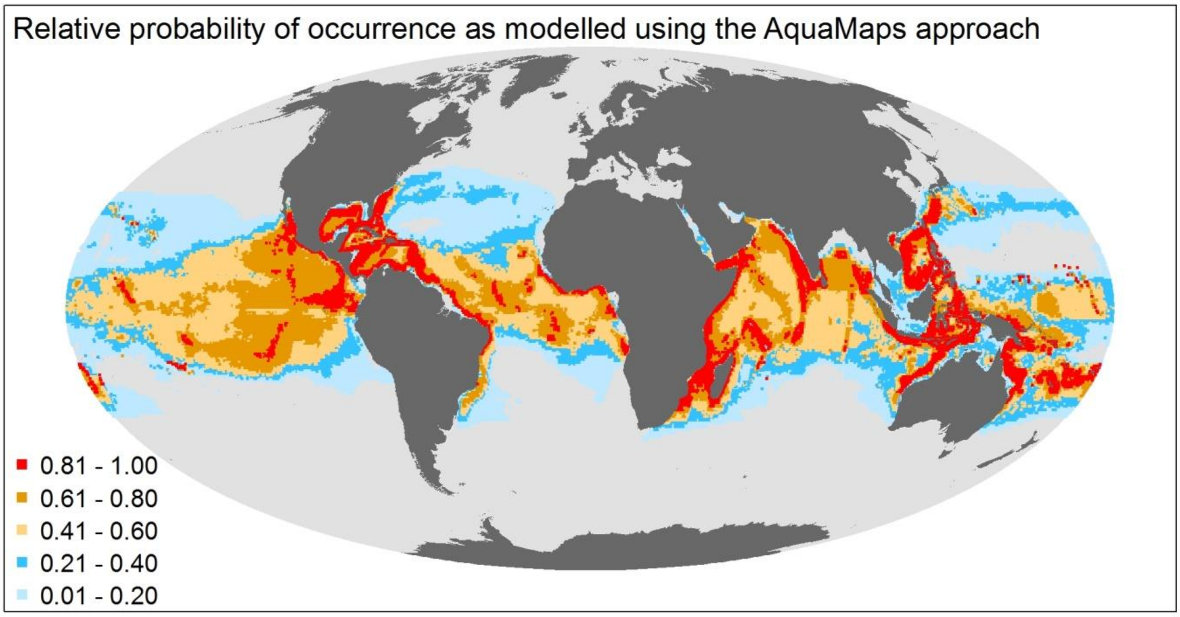

Figure 10. Modelled distribution map for the melon-headed whale.

All ten maps can also be viewed in an 'interactive PDF' (in e-supplement to this annex, and previewed in Figure 11). To date, two species (the sei and sperm whales) can also be viewed on the *Ocean Data Viewer*[51]. For accessing the actual data layers (i.e. shapefiles), please refer to the metadata.

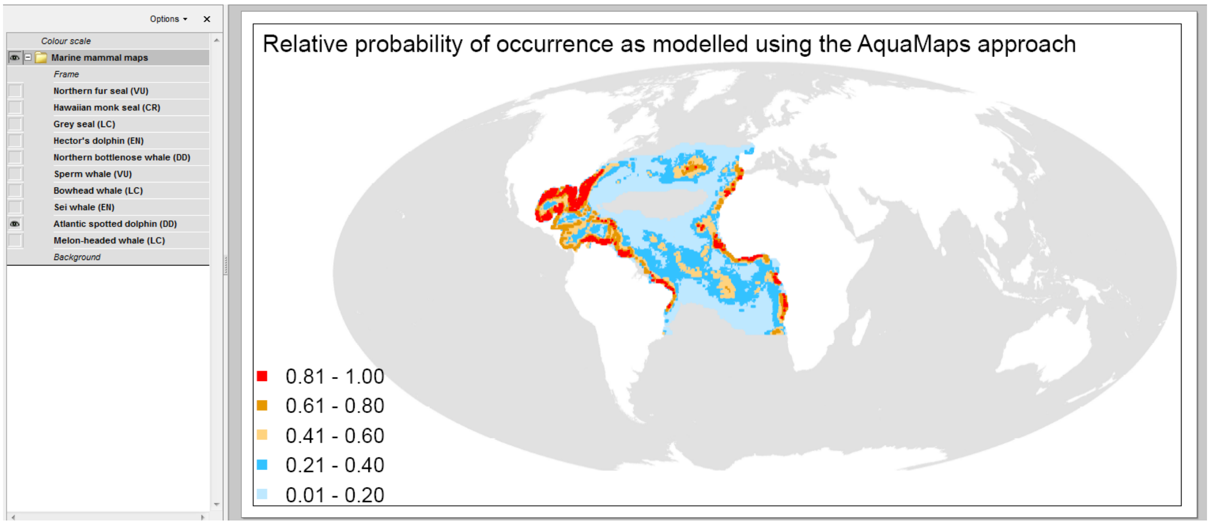

Figure 11. Preview of the interactive PDF (e-supplement) showing distribution maps for ten marine mammal species.

[51] http://data.unep-wcmc.org/. More species will be added to the Ocean Data Viewer interface in due course.

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