

Chapter 35. Extent of Assessment of Marine Biological Diversity

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1. Introduction

This chapter provides a summary of currently assessed marine biodiversity in terms of its coverage for the most conspicuous and well known taxonomic groups, particular ecosystems, and large geographic regions. Assessments will be focused on the evaluation of the state of knowledge of marine biodiversity; however, for some groups, such evaluations are provided indirectly by studies aimed to establish threat and or risk status. The groups that have been summarized globally are the sea mammals (cetaceans and pinnipeds), seabirds, sea turtles, sharks, tunas, billfish, corals, and plankton. The special ecosystems are seamounts, vents, and seeps. Regional summaries of coverage of assessments are provided whenever possible for large basins, such as North Atlantic, South Atlantic, North Pacific, South Pacific, Indian Ocean, Arctic Ocean, and Southern Ocean. However, in some cases, information is compiled by countries (e.g., Canada) when these have more than one basin, or by large continents (e.g., South America) which share a history of surveys and exploration. After each of the sections, a global analysis of the status of knowledge of marine biodiversity is summarized within a few synthesis graphs. About 40 scientists contributed to this effort, each within their area of expertise and specified for each subsection. Supplementary material providing a list of assessments with date, special area, habitat, taxonomic groups, and web information has also been compiled for a few of the regions (Caribbean, Europe, Gulf of Mexico, the Southern Ocean and Sub-Saharan Africa) and States (China, India and Japan), as well as for vents and seeps ecosystems and for turtles (Appendix I). In addition, a complete reference list for further reading for each of the taxonomic groups and regions is provided (Appendix II).

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2. Groups summarized globally: Cetaceans, pinnipeds, seabirds, sea turtles, sharks, tunas, billfish, corals, seamounts, vents and seeps.

2.1 Marine Mammals

Global assessments of marine mammal distributions are limited by geographic and seasonal biases in data collection, as well as by biases in taxonomic representation due to rarity and detectability. In addition, not all data collected have been published in open-access repositories, thus further constraining our ability to develop comprehensive assessments. Given the financial, logistical and methodological challenges of mounting surveys, especially for animals that spend most of their time underwater, assessments have been most extensive and intensive on the coastal shelves and continental slopes along the coastlines of developed countries (Kaschner et al., 2012 & Figure 1A). Ship-board surveys of large ocean areas have been and continue to be carried out in the Southern Ocean and North Pacific under among others, the auspices of the International Whaling Commission, focusing on those whales previously subject to commercial whaling. Advances in satellite telemetry are helping to fill in some gaps in offshore areas for both cetaceans and pinnipeds (Block et al., 2011).

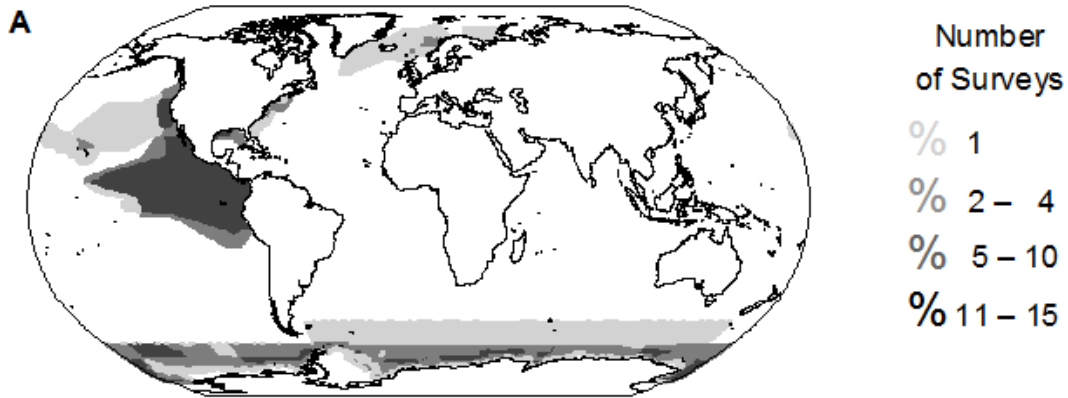
However, the remaining geographic biases in sampling coverage are very apparent, for example, in the map portal Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations OBIS-SEAMAP (<http://seamap.env.duke.edu>), which is an online data portal compiling occurrence records of higher vertebrates living in the marine environment (Halpin et al., 2009), where the majority of species observation records fall within the coastal shelves and continental slopes of the Northern Hemisphere. Around 95 per cent of the marine mammal observations published on the portal are from inside the 200-nautical-mile (nm) exclusive economic zone (EEZ), while ~5 per cent are in areas beyond national jurisdiction (ABNJ). A recent analysis of global coverage of cetacean visual line-transect survey coverage showed that only ~ 25 per cent of the world's ocean area had been covered by systematic surveys by the year 2006, and only 6 per cent had been covered frequently enough to be able to detect population trends (Kaschner et al., 2012). Pinniped and cetacean populations are monitored fairly frequently in the United States of America, European and Southern Ocean waters; more than half of the total global line-transect effort from 1978 – 2006 was in areas within the national jurisdiction of the United States (Kaschner et al., 2012) and ~35 per cent of all marine mammal observations held in OBIS-SEAMAP are from within the 200-nm EEZ of the United States.

Geographically, the largest gaps in sampling coverage are in the Indian Ocean and the temperate South Atlantic and South Pacific, where comparatively few dedicated surveys have been conducted. In the Southern Hemisphere, surveys have been carried out mostly in the EEZs of Australia, New Zealand, Chile, Argentina, and South Africa where more than 50 per cent of the world's species are found, and endemism is relatively high. Seasonally, most data collection using standard visual monitoring methods is concentrated in the summer as poor weather conditions seriously lower detectability,

but again, satellite telemetry and passive acoustic monitoring are helping to fill in some of the temporal gaps. Although passive acoustic monitoring can be very useful in detecting the calls of certain species, and thus help determine their presence in a region, during seasons of poor visibility or low survey effort, such monitoring cannot yet be used routinely for the development of abundance or density estimates.

Sampling effort and reporting is also highly variable for different species. For example, although OBIS-SEAMAP currently contains a total of >560,000 marine mammal occurrence records covering 106 species of the roughly 120 marine mammal species (~88 per cent), the data sets are uneven, with no records available of some uncommon species (~12 per cent) and fewer than 10 records available for others (~14 per cent). Overall, the distributions of some well-known species, such as the humpback whale (*Megaptera novaeangliae*) and the harbour porpoise (*Phocoena phocoena*), have been studied extensively and are well established; they are based on sightings and strandings or analyses of catch data. Relatively large proportions of the known ranges of these species are being monitored frequently, using different survey techniques (Kaschner et al., 2012). Similarly, at-sea movements and occurrence of other species, such as the southern and northern elephant seals (*Mirounga leonina*, *M. angustirostris*), have been investigated in considerable detail, using data loggers and satellite tracking (Block et al., 2011). In contrast, the information on some species is limited and patchy due to their rarity and/or cryptic behaviour. Some have rarely, if ever, been seen alive and are known only from a few stranding records (e.g., Perrin's beaked whale, *Mesoplodon perrini*).

Assessments of marine mammal species distribution and status derived from available data sets must be viewed in comparison to survey effort to control for unsurveyed regions or areas where observation data have not been shared with open-access information systems (Figure 1A). Accumulated data sets and understanding of marine mammal species distributions are improving, but any interpretation of the state of knowledge needs to take account of the significant biases, as noted. In summary, assessment of marine mammals globally is far from comprehensive, with abundance estimation and trend analysis at the population level limited to relatively few species in particular geographic regions, and for some species even such basic information as their actual range of occurrence is still lacking.



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 1A. Global coverage of visual cetacean line-transect survey effort (Frequency of coverage) (from Kaschner et al., 2012). See also the OBIS SEAMAP data available through <http://seamap.env.duke.edu>.

2.2 *Seabirds*

BirdLife International is the International Union for the Conservation of Nature (IUCN) Red List authority for birds, and assesses the status, trends and threats of all Critically Endangered seabirds each year, as well as species thought to warrant immediate uplisting. In addition BirdLife International carries out a comprehensive assessment of all 350+ species of seabird every four years. Some seabird populations and/or species lack population monitoring altogether, resulting in unknown population trends for 53 seabird species on the IUCN Red List (Croxall et al., 2012). The International Waterbird Census (IWC) includes certain seabird species. It has run since 1967 and today covers over 25,000 sites in more than 100 countries. Results are reviewed and published in Waterbird Population Estimates, which assess the trends and 1 per cent thresholds for over 800 species and 2,300 biogeographic populations worldwide.

At the global and regional levels many Multilateral Environmental Agreements (MEAs) include priority species lists for which aspects of status, trends and threats are supposed to be assessed. Seabirds are included on some of these lists and are used as indicators for assessing the state of the marine environment. Those currently most actively undertaking work include the Agreement on the Conservation of Albatrosses and Petrels (ACAP) (29 species), the Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (the European Union (EU) Birds Directive (all seabirds in the EU), the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) (9 species), the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) (82 species), the Convention for Protection against Pollution in the Mediterranean Sea (Barcelona Convention) (14 species), the Convention on the Conservation of Migratory Species of Wild Animals (CMS) (20 seabird species on Annex I; 50 on Annex II), the Convention on the Conservation of European Wildlife and natural habitats (Bern

Convention) (over 30 species), the Convention on the Protection of the Marine Environment of the Baltic Sea (HELCOM) (11 species), the Convention on the Protection of the Black Sea against Pollution (Bucharest Convention) (2 species), the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (7 species), the Conservation of Arctic Flora and Fauna (CAFF) (3 species), the North American Agreement on Environmental Cooperation (1 species), and the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) (6 species). Other MEAs that have this remit but are not yet active include the Nairobi Convention for the Protection, Management and Development of Marine and Coastal and Environment of the Western Indian Ocean Region (the Nairobi Convention) (47 species), the Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment (Jeddah Convention) (lists not yet provided by contracting parties), Convention for Cooperation in the Protection, Management and Development of the Marine and Coastal Environment of the Atlantic Coast of West, Central and Southern Africa Region (Abidjan Convention) (considering adding a species list), and the Convention for the Protection and Development of the Marine Environment in the Wider Caribbean Region (Cartagena Convention) (5 species). These MEAs (and other processes) have led to the development of individual species management plans, which often outline how (and by whom) monitoring of status, trends and threats can be addressed.

Numerous online databases have pooled seabird data at regional or global scales (as well as national programmes); these include data for:

- Colonies – Sea Around Us Project, BirdLife International World Bird Database and Marine E-atlas, Global Seabird Colony Register, Circumpolar Seabird Data portal, New Zealand National Aquatic Biodiversity Information System (NABIS)
- Productivity - Pacific Seabird Monitoring Database.
- Tracking - Seabirdtracking.org, OBIS-SEAMAP, Movebank, seaturtle.org, Tagging of Pacific Predators (TOPP), British Antarctic Survey, CNRS-Chize
- At-sea surveys - European Seabirds at Sea, North Pacific Seabird Portal, Australia Antarctic Division, Royal Navy Birdwatching Society, OBIS-SEAMAP, Atlas of Seabirds @ Sea, eBird, North Pacific Pelagic Seabird Database, Global Biodiversity Information Facility.
- Threats - the New Zealand Threat Classification System: conservation status of 473 taxa assessed. For seabirds, perhaps the world second largest in terms of number of species assessed (Robertson et al., 2013).

The BirdLife International Marine Important Bird Areas (IBA) e-Atlas provides a site-based information portal for seabird conservation. This first global network of over 3,000 sites covers 6.2 per cent of the world's oceans and was compiled by BirdLife International drawing on work from 1,000 seabird scientists, government ministries and secretariats of conventions. The World Seabird Union (comprised of 22 seabird

organizations) has established the Seabird Information Network aiming to showcase, and link, different global seabird databases.

2.3 Marine Turtles

The primary global assessment framework for marine turtle species is the IUCN Red List of Threatened Species™ (www.iucnredlist.org). The IUCN Marine Turtle Specialist Group (MTSG), one of the IUCN/Species Survival Commission's specialist groups, is responsible for conducting regular Red List assessments of each marine turtle species on a global scale. Currently the Red List identifies the olive ridley (*Lepidochelys olivacea*) as Vulnerable, the loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) turtles as Endangered, the Kemp's ridley (*Lepidochelys kempii*), hawksbill (*Eretmochelys imbricata*), and leatherback (*Dermochelys coriacea*) turtles as Critically Endangered, and the flatback turtle (*Dermochelys coriacea*) as Data Deficient.

To address the critical issue of geographically variable population traits in marine turtle species, the MTSG developed an alternative assessment framework and a new approach to Red List assessments that better characterize variation in status and trends of individual populations (Wallace et al., 2010), which results in official Red List categories for subpopulations in addition to the single global listing.

To address the challenges presented by the mismatched scales of global Red List assessments and regional/population-level variation in status, the IUCN Marine Turtle Specialist Group (MTSG) convened the Burning Issues Working Group of marine turtle experts who developed (1) regional management units (RMUs) (i.e., spatially explicit population segments defined by biogeographical data for marine turtle species) as the framework for defining population segments for assessments (Wallace et al., 2010). These RMUs are functionally equivalent to IUCN subpopulations, thus providing the appropriate demographic unit for Red List assessments. The Group also developed (2) a flexible yet robust framework for assessing population viability and the degree of threats that could be applied to any population in any region, and (3) a "conservation priorities portfolio" for all RMUs, with globally included identification of critical data needs by RMUs, as well as individual population risk and threats criteria, and that reflects the wide variety of conservation objectives held by different stakeholders depending on institutional or regional priorities. South Asia had the highest proportion of RMUs categorized as requiring critical data needs (~40 per cent), followed by the West Indian Ocean (25 per cent) and Australasia (20 per cent). Similarly, population risk and threats scores for RMUs in the Indian Ocean were associated with the lowest availability and quality of data among ocean basins.

Among population risk criteria, insufficient information was available to assess recent and long-term trends for roughly 25-30 per cent of all RMUs. Among threats, climate change was scored "data deficient" in two-thirds of all RMUs, while pollution and pathogens were scored "data deficient" in more than half of all RMUs. These results demonstrate the need to enhance data collection and reporting on population trends,

as well as current and future impacts of climate change and pollution/pathogens on marine turtles.

In addition to the two primary global assessment frameworks described above, several other global status assessments exist for marine turtles. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Convention on the Conservation of Migratory Species of Wild Animals (CMS, or Bonn Convention) include all marine turtle species in their lists, meaning that international trade in any products of any marine turtle species is prohibited and marine turtles are categorized as being in danger of extinction throughout all or a significant proportion of their range.

National laws to assess and protect endangered species can also result in global assessments. For example, all marine turtle species (except the flatback, *Natator depressus* which does not appear in the United States territorial waters) are listed globally as either Endangered or Threatened under the United States Endangered Species Act. Recently, the United States designated “distinct population segments”—which are similar to the RMUs and IUCN subpopulations described above—for loggerhead turtles (*Caretta caretta*) and listed all populations as either Threatened or Endangered. In addition, global status reviews are performed every five years for all marine turtle species listed under this act in the United States (Wallace, 2010).

Regional assessments offer more detailed views of marine turtle status, significant threats, and data gaps. Three noteworthy examples of regional marine turtle status are highlighted here. First, the Wider Caribbean Sea Turtle Conservation Network (WIDECAST, www.widecast.org) generated an “atlas” of marine turtle nesting sites, legal protection, and other relevant information for more than 40 countries and territories in the Wider Caribbean. Second, regional members of the IUCN Marine Turtle Specialist Group conducted a comprehensive assessment of the distribution, threats, and conservation priorities with regard to marine turtles in the Mediterranean. Third, the Indian Ocean-Southeast Asia Marine Turtle Memorandum of Understanding (IOSEA, www.ioseaturtles.org) has produced status and threats assessments of two species (loggerheads and leatherbacks) across more than 30 countries in the Indian Ocean and Southeast Asia. Assessments of marine turtle status at national and local levels occur around the globe, but a complete review is beyond the scope of this section (see Appendix I – Turtles: Summary of existing assessment frameworks and resources for marine turtles at global and regional scales).

In general, an urgent need remains for enhanced monitoring and reporting of marine turtle population status and trends, as well as of threats to marine turtles globally. Although much information exists in some regions (e.g., Wider Caribbean, Mediterranean, North America), significant data needs are apparent in other regions (e.g., West and East Africa, North Indian Ocean, Southeast Asia). Regional and global efforts to compile all available information in such regions are vital to filling these data gaps. Nonetheless, significant efforts to quantify fundamental marine turtle

demographic rates and processes (NRC, 2010) are still required to improve assessments of marine turtle status at global, regional and local scales (Wallace, 2011).

2.4 *Sharks, Rays, and Chimaeras*

Sharks, rays and chimaeras comprise the Class Chondrichthyes. This group is highly diverse (at least 1,200 valid species) and occur in a broad range of habitats, so a wide range of approaches has been taken to assess the status of individual populations. The most publicly available assessments for chondrichthyans are available from the IUCN Red List. The IUCN Species Survival Commission's Shark Specialist Group (SSG), is a global network of experts in the biology, taxonomy, and conservation of sharks, rays, and chimaeras which continuously conducts global and regional assessments of the Red List Status of chondrichthyans. Established in 1991, the SSG currently has more than 123 members from 33 countries collaborating to assess threat level, collate knowledge, highlight species at risk, and advise decision-makers on effective, science-based policies for sustainable use and long-term conservation (www.iucnssg.org). In 2011, using the 2001 IUCN Red List Categories and Criteria (version 3.1; <http://www.iucnredlist.org/technical-documents/categories-and-criteria>), a total of 1,041 chondrichthyan species had been assessed and their extent of occurrence mapped, highlighting considerable gaps in knowledge (Dulvy et al., 2014). A total of 487 out of the 1,041 species were categorized as Data Deficient, particularly in four regions: (1) Caribbean Sea and Western Central Atlantic Ocean, (2) Eastern Central Atlantic Ocean, (3) Southwest Indian Ocean, and (4) the South and East China Seas (Dulvy et al., 2014), and in 2014, the assessed number of species was raised to 1,088. Since assessments are considered out of date after ten years, a concerted effort has been initiated to reassess all species in support of the 2020 Aichi targets of the Convention on Biological Diversity's Strategic Plan for Biodiversity (e.g. North-East Pacific and Europe regions in 2014; Australia and Oceania planned for 2015).

The Red List Assessments are complemented by data from catch landings, fishery catch rates, fisheries stock assessments, fishery-independent surveys, transect surveys (divers, boats, and aerial), as well as increasing quantities of individual photographic identification data, satellite tracking data and population genetics data, which vary in availability, quality, and geographic and taxonomic coverage. These data collection programmes and research projects are also combined with historical ecological information and traditional knowledge-based assessments of the change in species distributions.

National catch landings data are reported annually to the Food and Agriculture Organization of the United Nations (FAO). From 2000 to 2009, 143 countries/entities reported shark, ray and chimaera catches to FAO. The taxonomic resolution of the global landed catch has improved, but remains poor. By 2010, only a small proportion (29 per cent) of the catch was reported to species level, the remaining bulk of the global catch reported at much coarser taxonomic levels, and around one-third of global catches reported at the taxonomic Class level (i.e. "Sharks, rays, skates, etc"). Among

the top shark fishing nations (Indonesia, India, Spain, Taiwan Province of China, Argentina, Mexico, United States of America, Malaysia, Pakistan, Brazil, Japan, France, New Zealand, Thailand, Portugal, Nigeria, Islamic Republic of Iran, Sri Lanka, Republic of Korea, Yemen), half (11) report 50 per cent or more of their catch at the species and genus level.

The taxonomic and geographic distribution of fisheries assessments of stock biomass and fishing mortality is very sparse. To date, we are aware of 41 stock assessments for 28 chondrichthyan species. The United States and Australia conduct most stock assessments; the majority conducted in the Atlantic Ocean (21), followed by the Indian Ocean (11) and 9 in the Pacific Ocean. Research surveys and shark control programmes are increasingly being used to assess the trajectory and status of shark and ray populations, particularly in the coastal waters of the United States, Europe, South Africa, New Zealand, and Australia. Many of these time series are ongoing and the specific assessment of the status of chondrichthyan is periodic and dependent on research funding.

Emerging technologies, such as satellite tags and acoustic tracking arrays, as well as the widespread availability of digital underwater photography, web-based database capability and photo identification systems, are providing information for better population estimates and refined geographic distributions. The miniaturization and longevity of electronic tags have revealed complex sex-biased migrations, migratory routes and infrequent but biologically important ocean transits connecting populations that were previously thought to be separate. The development of pattern-matching algorithms has transformed collections of photographs into mark-recapture methods for estimating local abundance and spatial dynamics of larger, more charismatic species, such as: White Shark (*Carcharodon carcharias*), Whale Shark (*Rhincodon typus*), and manta rays (*Manta birostris* and *M. alfredi*). Assessment approaches have been complemented by the rapid emergence of worldwide tissue-sampling and population genetics work that has led to an increasing understanding of the variation in gene flow and connectedness of populations within species, and increasingly the degree to which their ecology and life histories shape patterns of genetic relatedness. Genetic information is also increasingly used to assess the scale of the trade in shark fins and other valuable traded items, including the species composition of trade, and occurrences of illegal sale and trade (Abercrombie et al., 2005).

Assessments of long-term changes in distribution and population trajectories are increasingly being compiled from less formal sources of historical ecological information, including newspaper reports, trade records, and sightings. Compilations of museum records, newspaper reports and sightings have been used to reconstruct the former distribution of sawfishes, prompting conservation action. Assessments of historical landings and the traditional ecological knowledge of fishers have revealed a massive reduction in the diversity of chondrichthyan landed in Southeast Asian markets.

Key challenges that remain include continuing ongoing assessment activities, research surveys, and expanding assessments to include other species, not just the larger and

more charismatic species. Assessments would also need to be expanded to include lesser known species, which are often more threatened, particularly the rays and ray-like sharks, and the 90 obligate and euryhaline freshwater species. Geographically, greater attention would need to be paid to Central and South America, Africa, and South East Asia.

2.5 *Tuna*

As many tunas are commercially important fisheries species, most assessments are based on fisheries-dependent catch data, although these are occasionally augmented by fisheries independent datasets, such as larval trawls, aerial surveys and scientific catch surveys. Fisheries catch data have the potential for bias due to extrinsic factors, such as those that may influence fishing effort (e.g., fuel and fish prices; regulations on fishing times and areas; changes to gear that influences fishing efficiency over time), as well as lack of reporting of catch and/or effort, and changes in the distribution of tuna species that may cause changes in the interaction rates with individual fisheries (Collette et al., 2011). In addition to limitations in data on catch rates, data on basic biological parameters necessary for accurate stock assessments (e.g., growth rates, stock structure, size/age of maturity, natural mortality rates) are often poorly known, thus also affecting the accuracy of the assessments. These limitations have begun to be addressed through advances in scientific methodologies. Electronic and conventional tagging studies have shed light on all these biological parameters, and population genetic and micro-constituent studies have facilitated delineation of stock structure in many tuna species. In addition, traditional sampling methodologies, such as histological sampling of gonads, counting rings on hard parts, such as otoliths and fin spines, and cohort analysis have all provided information on growth rates and reproductive maturity schedules. However, collecting these data costs money, hence data, and therefore the assessments, are usually better for the tuna species that are more economically important.

Most tuna assessments are conducted through regional fisheries management organizations (RFMOs), a collection of national and other fishing parties that jointly manage shared fish stocks (Aranda et al., 2010). Five tuna RFMOs currently exist that regulate fisheries for their member States: the International Commission for the Conservation of Atlantic Tunas (ICCAT), regulates tuna in the Atlantic Ocean, the Inter-American Tropical Tuna Commission (IATTC), regulates tuna in the eastern tropical Pacific, the Western and Central Pacific Fisheries Commission (WCPFC), regulates tuna in the Western and Central Pacific Ocean, the Indian Ocean Tuna Commission (IOTC), regulates tuna in the Indian Ocean and the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), regulates southern Bluefin tuna (*Thunnus maccoyii*) throughout its range. In addition to assessments conducted through RFMOs, other international organizations such as the IUCN, the CITES, national governments and independent scientists also occasionally conduct assessments of various tuna species. Unlike RFMO assessments, which generally seek to assess stock health in relation to optimal fisheries yield, most other organizations conducting assessments on tunas

attempt to estimate extinction risk. As a result, RFMOs' and others' assessments may differ greatly in their evaluations of the health of tuna stocks.

The most commercially important tuna species have been assessed recently, either regionally or throughout their range by the above-mentioned tuna Commissions. The Bluefin tunas (Pacific [*Thunnus orientalis*], Southern [*T. maccoyii*] and Atlantic [*T. thynnus*]) have all had a full stock assessment within the last four years through their respective RFMOs. Likewise, Bigeye tuna (*T. obesus*), Yellowfin tuna (*T. albacares*), Albacore tuna (*T. alalunga*) and Skipjack tuna (*Katsuwonus pelamis*) have all been assessed regionally through the RFMO assessment process, as well as globally through the IUCN. Other species, such as Blackfin tuna (*T. atlanticus*) and Longtail tuna (*T. tonggol*) have not had full assessments conducted through their respective RFMOs, although localized assessments in part of their range may have been undertaken. RFMOs for these are the ICCAT for Blackfin tuna, and the IOTC and WCPFC for Longtail tuna.

Less is known on the stock status of tuna species for which there are only small, directed fisheries or for which most of the catch occurs as by-catch. Slender tuna (*Allothunnus fallai*), frigate tuna (*Auxis thazard*), and bullet tuna (*Auxis rochei*) all range widely, but formal assessments have not been conducted by RFMOs in each ocean basin. Black skipjack (*Euthynnus lineatus*), Kawakawa (*Euthynnus affinis*), and little tunny (*Euthynnus alletteratus*) are all regionally distributed (Eastern Pacific, Western Pacific and tropical Atlantic, respectively), and few data are available on range-wide catches over time; this is necessary for a full population assessment. However, the wide ranges of these six species, coupled with relatively low and localized exploitation, caused these species to be classified under "Least Concern" by the IUCN.

Although formal stock assessments have been completed for almost half of the tuna species (7 out of 15), few standardized data sets exist on catch rates over time for the remainder of the species. Improvements in the collection of fishery-dependent data or initiation of fisheries-independent data collection would be necessary to obtain accurate estimates of stock health. In the meantime, relatively stable catches over time for the unassessed species suggest that there is little immediate threat to the viability of any of these species.

2.6 Billfish

Billfish are epipelagic marine fishes distinguished by elongated spears or swords on their snouts. Most of the species have very large, ocean-wide or cosmopolitan ranges in tropical and subtropical waters and all are tied to the tropics for reproduction. However, the Swordfish extends into temperate waters. All are of commercial or recreational importance; hence our knowledge of their distribution comes largely from fisheries. Three species are restricted to the Indo-West Pacific: *Istiompax indica*, Black Marlin; *Tetrapturus angustirostris*, Shortbill Spearfish; and *Kajikia audax*, Striped Marlin. The

other three species of spearfish and the White Marlin, *Kajikia albida*, are restricted to the Atlantic Ocean.

Most of the species are well known and easily distinguished; fisheries records document their distribution. However, this is not the case for Black versus Blue Marlin or for the spearfish. The Atlantic Longbill Spearfish, *Tetrapturus pfluegeri*, was not described until 1963 and a second species, *T. georgii*, Roundscale Spearfish, although originally described in 1841, was not validated as a species until 2006. This species is easily confused with White Marlin (*Kajikia albida*), hence the exact distributions of these two species are not yet completely clear, but appear to include much of the North and South Atlantic. Due to overfishing, two billfish meet the IUCN Red List criteria for a threatened category, Vulnerable (Collette et al., 2011): *Makaira nigricans*, the Blue Marlin, and *Kajikia albida*, the White Marlin.

The ICCAT, operating since 1969, is the organization responsible for the conservation of tunas and tuna-like species in the Atlantic Ocean and adjacent seas including several species of billfishes including the White Marlin, Blue Marlin, Sailfish (*Istiophorus albicans*) and Longbill Spearfish. Studies carried out by the ICCAT are mostly focused on the effects of fishing on stock abundance and include data on biometry, ecology, and oceanography. In the tropical Atlantic, this responsibility is held by the Inter-American Tropical Tuna Commission (IATTC) operating since 1950.

2.7 Coral and coral reef assessments

Coral reefs are among the most charismatic of tropical marine ecosystems (Knowlton et al., 2010) and have been assessed globally under several frameworks. Interestingly, however, because they occur in complex shallow seas, the application of large scale oceanographic tools and observation systems on major vessels is impossible; at the same time, they are accessible to small-scale, small-vessel direct observation methods. Their visual attractiveness, ecological complexity and the growth of observational science due to the invention of SCUBA technology in the 1960s have made them a focus for direct observational methods by researchers. As a result, even in the most accessible of coral reef systems in the Caribbean, recent synthesis has found diversity of methods and incompatibility of datasets to be the norm (Jackson et al. 2014).

Coral reefs bear among the highest taxonomic diversity of any ecosystem, and at the same time reef science is relatively youthful. This has resulted in high fluidity in the taxonomy of reef species, in particular complex symbiotic organisms, such as corals, though some well-sampled groups such as, bony fish and molluscs have benefited from taxonomic work inherited from other ecosystems. At the same time, molecular techniques, such as barcoding, are showing high levels of un-described diversity in microbial and invertebrate communities, both major components of coral reef biota.

Nevertheless, the broad global patterns in marine biodiversity are well-described through patterns in indicator groups including corals, stomatopods, and fish. The Indo-Malayan region is a clear centre of diversity for coral reef taxonomic groups, resulting from a broad range of biodiversity-generating and -maintaining processes from short to long time scales (Roberts et al. 2002). Diversity assessments in other regions have, however, been less complete, but resulting in emerging evidence of elevated diversity in other regions, such as in Eastern Africa and the South China Sea. The Caribbean or tropical Atlantic region is highly depauperate in terms of species diversity compared to the Indo-Pacific, resulting from isolation mechanisms over tens of millions of years, as well as since the formation of the isthmus of Panama (Veron, 2000). Coral species have been assessed for the IUCN Red List of Threatened Species, resulting in over one-third of species being identified as Threatened, among the highest proportions of all taxonomic groups globally (See also chapter 43).

Most of the global level assessments of coral reefs are ecological in nature, or use higher taxonomic levels, such as genera for recording absolute or relative abundance. The principal variables used in reporting coral reef health include proportional cover for attached benthic taxa (e.g. hard coral cover, in percent), abundance or density per unit area for key mobile taxa (invertebrates and vertebrates) and biomass, particularly for fish. The establishment of the Global Coral Reef Monitoring Network (GCRMN) was in response to the largest global reef impact ever recorded: the 1998 El Niño event. The resulting series of GCRMN reports (Wilkinson 1999, 2000, 2002, 2004 and 2008) exemplify the challenges in continuing such a large effort. At the same time, remote sensing technologies and global threat datasets have been used to prepare global assessments of the health of coral reefs in the Reef at Risk publications of the World Resources Institute (Burke et al. 2011). The most recent reporting under the GCRMN has focused on regional level reporting, with the first major regional assessment focusing on the Caribbean (Jackson et al. 2014). In this regard, it matches the scope of regional assessment frameworks, which have included those for: (1) the Caribbean, such as the Atlantic and Gulf Rapid Reef Assessment (AGGRA), the Caribbean Coastal Marine Productivity (CARICOMP); (2) parts of the Pacific such as the Coral Reef Monitoring Activities in Polynesia Mana Node, Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF) and (3) parts of the Indian Ocean such as the Coral Reef Degradation in the Indian Ocean (CORDIO), all building on the governance frameworks that are the product of the United Nations Environment Programme (UNEP) Regional Seas programme established in 1974. Due to the popularity of coral reefs for SCUBA diving, volunteer and participatory monitoring are popular alternatives, with the most comprehensive one being that of Reef Check (Hodgson, 1999). In these, assessments are based on indicator species and estimates of variables such as benthic cover. Though variable in quality and coverage, the resulting data can be invaluable in broad scale scientific assessments of reef status. Coral reef areas with the least investment in assessments are those in poor developing countries with generally low national dependence on the sea (though they may have large sectors of society with high levels of livelihood/subsistence dependence on the sea, e.g. the Indian Ocean) and of

middle/low biodiversity and interest for international science. Coral reef areas with the most investment in assessments are dispersed throughout the Pacific and tropical Atlantic.

Cold-water or deep-water corals are found globally, but have been most extensively mapped in the North Atlantic, due to extension of fishing and exploration for seabed resources in that region, and New Zealand has undertaken significant coral mapping. With greatest development from 200-1,000 m, and on topographic promontories such as seamounts, they can form large reefs of several 100s of m across and 10s of m above the substrate, but are highly vulnerable to damage and changing chemical oceanographic conditions. Further discoveries on the distribution of cold water corals are continuing to be made, such as in the southern Indian Ocean (Cairns, 2007).

Coral reefs are mentioned as a model ecosystem under Aichi Target 10 of the Convention on Biological Diversity (CBD) (to reverse impacts on climate-sensitive ecosystems). The search for “Essential Biodiversity Variables” (EBVs) to support monitoring for such targets and commitments is gaining momentum, and there is recognition that coral reefs may provide one of the ten globally-consistent sources to support this process, and not only with respect to biodiversity - greater recognition of the ecosystem services contributed by coral reefs (to communities, global tourism, and national/global economies and trade) should secure resources for monitoring of the ecosystem processes/indicators that underpin those services and goods, incentivizing monitoring and assessment to manage them for future benefit. In parallel with the CBD, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystems services (IPBES), and the Sustainable Development Goals may generate increased justification for upscaling coral reef assessments globally.

2.8 *Plankton*

At the global level, the seasonal pattern of Chlorophyll *a* is the best known and most studied phytoplankton-related variable in most marine ecosystems. Long-term studies on seasonal changes in phytoplankton diversity and abundance have been more localized geographically. The Western Channel Observatory (WCO) run by the Plymouth Marine Laboratory and the Marine Biological Association (United Kingdom) holds a marine biodiversity reference dataset for the Western English Channel with some of the longest time-series in the world for zooplankton and phytoplankton. At the Chesapeake Bay, a monthly, continuous 20-year phytoplankton database exists. In the Baltic Sea, historical phytoplankton data on community composition shows long-term changes in comparison to the early 1900s (Hällfors et al., 2013). However, much less is known about how changing diversity affects the productivity and functioning of marine food webs as well as the drivers behind these changes. Some global changes in diversity have been addressed based on the Continuous Plankton Recorder (CPR) data.

Perhaps the longest time-series sets exist for planktonic organisms (zooplankton and fish larvae) from the North-eastern Atlantic (North and Baltic Seas, English Channel and Bay of Biscay). It is important to note that plankton monitoring has extended to practically all the regions of the European coast due to the implementation of relatively recent legislation (e.g., the European Water Framework Directive). In this way, the study of plankton taxonomic composition and dynamics is being conducted in many areas that have been poorly studied or not studied at all. Surveys on micro-, nano-, picoplankton also exist, but these are spatially more restricted and substantially more comprehensive.

Some of the early formal accounts on zoobenthos date back to the famous Michael Sars expedition in the Atlantic in 1910, amended with several major contributions from Census of Marine Life activities (such as “Patterns and processes of the ecosystems of the northern mid-Atlantic”, the Mid-Atlantic Ridge Ecosystem Project (MAR-ECO), and the global project Census of Marine Zooplankton) about a century later and introducing innovative identification techniques involving molecular biology.

2.8.1 The Continuous Plankton Recorder (CPR) survey

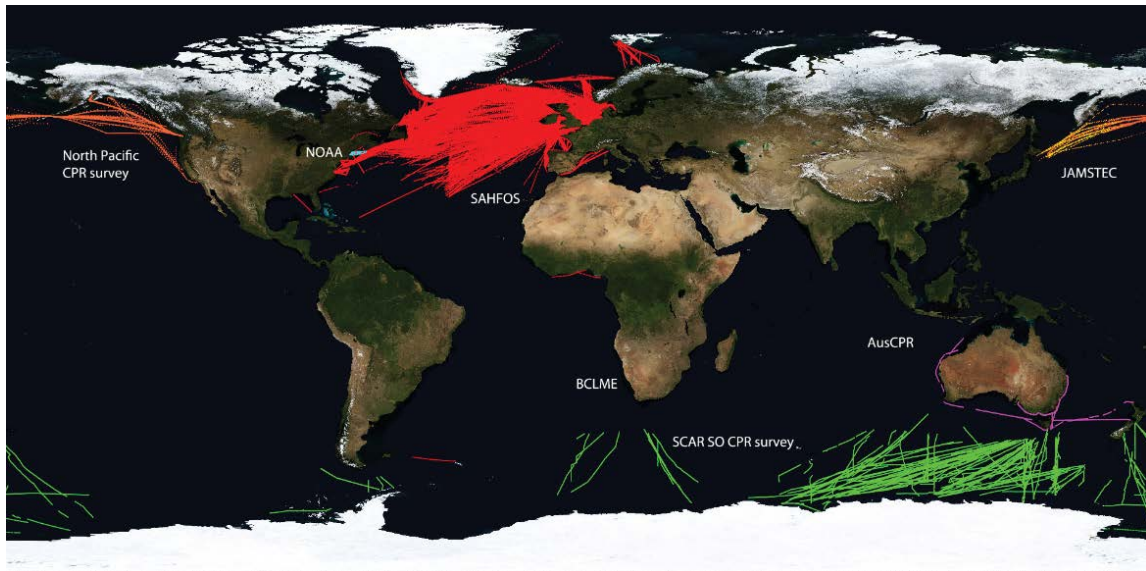
The Continuous Plankton Recorder (CPR) survey is recognized as the longest sustained (operating since 1931) and geographically most extensive marine biological survey in the world. The dataset comprises a uniquely large record of marine biodiversity covering ~1,000 taxa over multi-decadal periods. The survey determines the abundance and distribution of microscopic plants (phytoplankton) and animals (zooplankton, including fish larvae) in our oceans and shelf seas. Using ships of opportunity from ~30 different shipping companies, it obtains samples at monthly intervals on ~50 trans-ocean routes. In this way the survey autonomously collects biological and physical data from ships covering ~20,000 km of the ocean per month, ranging from the Arctic to the Southern Ocean. The survey is an internationally funded charity with a wide consortium of stakeholders.

Plankton are collected on a band of silk and subsequently visually identified (~1,000 taxa) by experts from around the world. Additionally, over the last decade the CPRs have been equipped with modern chemical and physical sensors, as well as molecular probes, to provide an array of additional information about our changing oceans. The final stages in the operation of the survey are the archiving of the resulting data and samples and interpreting the results at its central hub in Plymouth, United Kingdom. Strict quality control procedures are maintained for all CPR activities to ensure the integrity and long-term value of the programme. The database and sample archive together provide a resource that can be utilized in a wide range of environmental, ecological and fisheries-related research, e.g., molecular analyses of marine pathogens, modelling for forecasting and data for incorporation in new approaches to ecosystem and fishery management. Since the first tow of a CPR on a “ship of opportunity” in 1931, more than 6 million nautical miles of sea have been sampled and over 100 million data entries have been recorded.

Over the last eight decades the purpose of the survey has also co-evolved, with changing environmental policy, from purely monitoring plankton distributions to addressing and providing indicators for major marine management issues ranging from fisheries, harmful algal blooms, biodiversity, pollution, eutrophication, ocean acidification and climate change. For example, the CPR survey has documented a northerly shift of 1,000 km of marine organisms around Europe associated with climate change over the last four decades, with large ramifications for the European fishing industry. In the Arctic, the CPR survey recently recorded the first modern trans-Arctic migration of a diatom species (*Neodenticula seminae*) related to declining ice coverage (Reid et al., 2007; Edwards et al., 2012).

This diatom species, normally found in the Pacific Ocean, has been absent from the North Atlantic for over 800,000 years; perhaps it signifies the rapidity and unprecedented nature of climate change in the Arctic over recent geological history (Reid et al., 2008). In 2011, the Sir Alister Hardy Foundation for Ocean Science (SAHFOS), along with 12 other research organizations using the CPR from around the world, formed a Global Alliance of CPR surveys (GAC) with the aim of training new surveyors, producing a global ocean status report, capacity-building and developing a global plankton database. This global network of CPR surveys now routinely monitors the North Sea, North Atlantic, Arctic, North Pacific and Southern Ocean.

New surveys are underway in Australian, New Zealand, Japanese and South African waters; a Brazilian and an Indian Ocean survey are under development (Figure 2). These surveys provide coverage of large parts of the world's oceans, but many gaps still exist, particularly in the South Atlantic, Indian and Pacific Oceans. This global network also brings together the expertise of approximately 50 plankton specialists, scientists and technicians from 12 laboratories around the world. Working together, centralizing the database and working in close partnership with the marine shipping industry, this global network of CPR surveys with its low costs and new technologies makes the CPR an ideal tool for an expanded and comprehensive marine biological sampling programme. The database and website can be accessed via www.sahfos.ac.uk (Edwards et al., 2012).



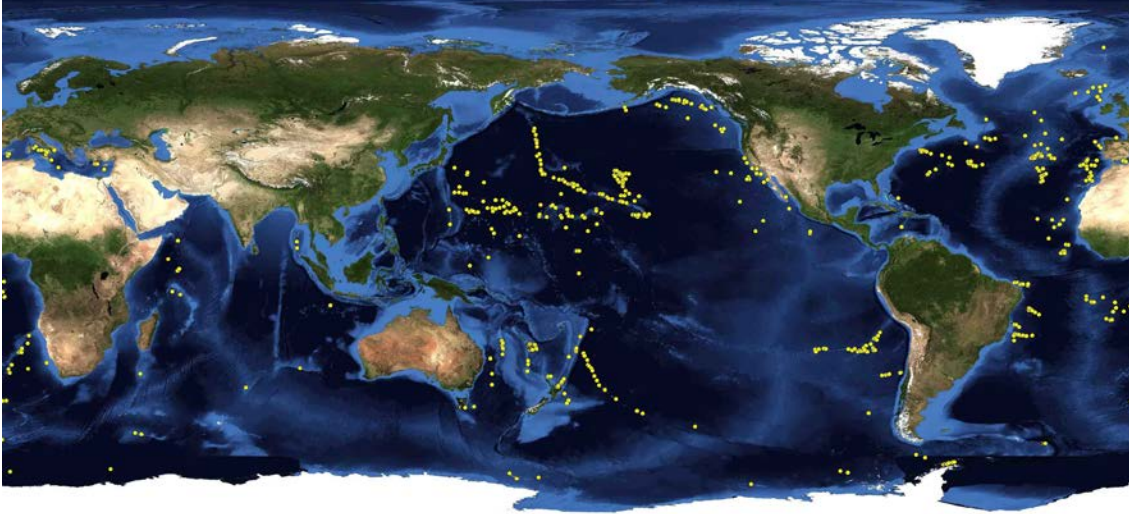
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 2. Start of sustained open-ocean biological time series and records (temporally broken and coastal time series are not included) plotted along the global mean SST time series from 1900 (Hadley Centre). Note that the majority of the time series are less than 30 years long. Station P (North Pacific); VICM (Vancouver Island Continental Margin time series); NMFS (National Marine Fisheries Service collection); BATS (Bermuda Atlantic Time Series Study); HOT (Hawaii Ocean Time Series program); Iberian coastal time series (North Coast of Spain); SO CPR survey (Southern Ocean CPR survey); AMT (Atlantic Meridional Transect); AZMP (Atlantic Zone Monitoring Program) (Edwards et al., 2010).

2.9 Seamounts

Several global seamount databases have been compiled, including the Seamount Catalogue (mainly geological), Seamounts Online (SMOL) (biological) and the Seamount Ecosystem Evaluation Framework (SEEF) (ecological) (Kvile et al., 2014). There are also detailed national datasets on seamount location and faunal composition, such as off New Zealand, the Azores, and for the western South Pacific (Allain et al., 2008). These databases and knowledge of seamounts have benefited from increased research on seamounts in the early 2000s by New Zealand, the United Kingdom, the United States, Japan, Australia, Portugal (Azores), among other countries, including the international CenSeam project of the Census of Marine Life (Clark et al., 2010).

A total of 684 seamounts have data recorded in the SEEF and SMOL up to the end of 2012. Their spatial distribution is: 458 in the Pacific Ocean, 164 in the Atlantic Ocean, 22 in the Mediterranean Sea, 12 in the Indian Ocean and 28 in the Southern Ocean. Their distribution is shown in Figure 3.



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 3. The distribution of seamounts with geological or biological sample data (sources: SEEF and SMOL).

The seamounts have a mixture of data types: all have geological information, and 54 per cent have had some level of biological investigation (Kvile et al., 2014). Overall, the seamounts in the North Atlantic Ocean and Mediterranean Sea have been the most studied; other oceans are typically patchy. For example, in the Pacific Ocean, over 60 per cent of seamounts in the database had biological data, but extensive sampling was focused on a few areas: on the Nazca and Sala y Gomez chains in the eastern South Pacific, around New Zealand and southern Australia in the southwest Pacific, and off parts of Hawaii, Alaska and the west coast of the United States in the North Pacific.

The last decade has seen a dramatic increase in the number of seamounts being surveyed. This has in part been due to efforts by the fishing industry to find new fish stocks, but also by major national or international (such as the Census of Marine Life project CenSeam) research programmes carrying out biodiversity surveys (see Figure 4, from Kvile et al., 2014). The CenSeam data can be accessed through the OBIS portal (www.iobis.org) by selecting the Seamounts Online database.

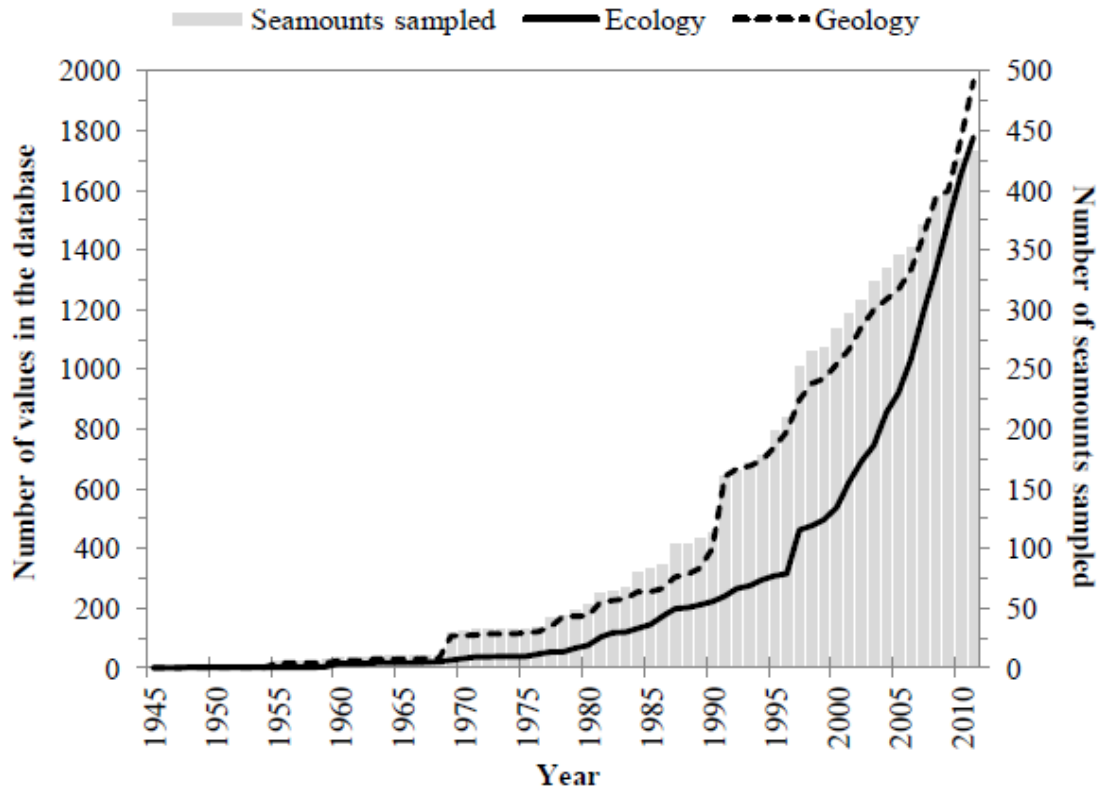


Figure 4. The cumulative number of seamounts explored over time (from Kvile et al., 2014).

Biological surveys of seamounts vary considerably in the methods and equipment used. In the North Atlantic, off the west coast of the United States, and in the North Pacific, remotely operated underwater vehicles (ROVs) and manned submersibles have been used to carry out extensive survey work. However, these tools tend to focus sampling on the mega-fauna, the large taxa that are clearly visible to the eye or camera equipment. Fish trawls have been used on many seamounts, and although these sample fish very effectively, they are poor at retaining fragile or small invertebrates. Off New Zealand and Australia, epibenthic sledges have been used on seamounts, which tend to catch a wide size range down to macroinvertebrates. Typically, a combination of sampling gear is necessary to adequately describe the benthic biodiversity on seamounts.

However, globally, a very low proportion of the large number of seamounts have been sampled. Of the nearly 450 seamounts sampled, relatively good data exist only for 300, and few of these are in equatorial latitudes, or deeper than about 2,000 m. Therefore, much about the structure, function and connectivity of seamount ecosystems remains unexplored and unknown. Continual, and potentially increasing, threats to seamount resources from fishing and seabed mining are creating a pressing demand for research to inform conservation and management strategies. To meet this need, intensive scientific effort in the following areas would be needed: (1) Improved physical and biological data; of particular importance is information on seamount location, physical

characteristics (e.g., habitat heterogeneity and complexity), more complete and intensive biodiversity inventories, and increased understanding of seamount connectivity and faunal dispersal; (2) New human impact data; these should encompass better studies on the effects of human activities on seamount ecosystems, as well as monitor long-term changes in seamount assemblages following impacts (e.g., recovery); (3) Global data repositories; there is a pressing need for more comprehensive fisheries catch and effort data, especially on the high seas, and compilation or maintenance of geological and biodiversity databases that underpin regional and global analyses; (4) Application of support tools in a data-poor environment; conservation and management will have to increasingly rely on predictive modelling techniques, critical evaluation of environmental surrogates as faunal “proxies”, and ecological risk assessment.

2.10 Vents and seeps

Since the discovery of hydrothermal vents and continental margin seeps in 1977, many animals found there were recognized as new to science, often at higher taxonomic levels. A recent assessment suggested that about 70 per cent of vent animals and 40 per cent of seep species now known are endemic to these habitats (German et al., 2011). In addition, many animals displayed unusual adaptations to habitats of reduced chemical compounds and physiological stresses. Systematic studies have generated many dispersed publications and some compilations have examined evolutionary patterns in a larger taxonomic group, ecological phenomena within a seep or vent region, and biogeographic pattern analyses. In this Assessment, only the most recent of these compilations are presented.

The InterRidge Vents Database is an important tool for metadata on hydrothermal vent sites that is currently maintained in an open-source content-management system in which updates depend on researcher input (Beaulieu et al., 2013). Over 500 confirmed and inferred referenced locations are listed. In the last decade, vent discoveries in arc and back-arc settings increased the known vent fields within exclusive economic zones. No biological or collection information is listed, hence it is a site for geographic information only. No similar information for seeps and other chemosynthesis-based habitats exists. The most recent map for locations of seeps globally appears to be that of Seuss (2010).

The Census of Marine Life (CoML) sponsored the eight-year project called Chemosynthetic Ecosystem Science (ChEss), with a primary focus to document the distribution of diversity in deep-water chemosynthetic ecosystems. The development of the ChEss database remains ongoing, but it is currently linked to OBIS; however, they are faunal lists and must be manipulated for site or taxonomic comparisons. Assessments emerging from use of the database are underway, but many are specific to faunal groups or regions.

To facilitate work in the field and laboratory, a handbook of vent fauna that assimilated most of the taxonomic papers and locality information related to hydrothermal vent fauna is available. The format of the book is a page for each species with a brief description, drawings or photographs and distribution information; it covers over 500 species in 12 phyla. No overall assessment of diversity is presented, but managers will find useful information on the species in their area of interest.

The ChEss Database has been used to formulate an assessment of the drivers of biogeographic patterns in vent faunas. The assessment focuses on historical relationships and centres of diversity. The approach uses network analysis and is a high-quality assessment of patterns. Another similar analysis for seep faunas of the equatorial Atlantic highlights discoveries on the western African margins and points out regions that still need investigation. Both datasets are available through IFREMER, France.

An overall assessment of vent and seep faunal diversity distribution and major drivers has yet to be executed. Exploration of these habitats is still underway, as biogeographic analysis shows major gaps in knowledge. Because of the close relationship of seeps on continental margins to areas of resource exploration interest (oil and gas, methane hydrates), assessment of the nature of diversity and its role in ecosystem function is important before potential alteration and/or destructions takes place. Similarly, growing interest in the metals associated with hydrothermal vent deposits may drive more work to define diversity patterns at vent habitats, as well as their relationships with other chemosynthesis-based habitats (See Appendix I-Vents and seeps: Major Inventories Available for Vent and Seep Habitats and Faunas). At present, many deep sea research initiatives have teamed up in INDEEP (International Network for Scientific investigation of deep-sea ecosystems) with the goal of providing a framework that will allow coordinated efforts in deep sea research across all its habitats while reaching out scientific results to managers and society.

3. Regional summaries of coverage of assessments: Arctic, North Atlantic, North Pacific, Indian, South Atlantic, South Pacific, and Southern Ocean

The following regional summaries are largely based on the work carried out by the network of National and Regional Committees of the Census of Marine Life (O'Dor et al., 2010; Costello et al., 2010). In this summary, the Caribbean and Mediterranean Seas as well as the Gulf of Mexico are included in the North Atlantic section. There are a few gaps in terms of geographic coverage (e.g. the Pacific coast of the Russian Federation, the Atlantic coast of Africa) due to lack of information or difficulties obtaining the data. However, a complete global analysis including all of the world's oceans was carried out using data from OBIS and presented in part 3 of the chapter.

3.1 *The Arctic*

Despite more than a century of observations on the Arctic's marine life, information on basic species inventories, as well as a quantitative synthesis, has remained fragmented until recently; however, some areas are still poorly known. Renewed interest in marine biodiversity generated by activities, such as those of the CBD, the Census of Marine Life and the International Polar Year, has begun to change this situation, but it is a slow process. At best, we are now armed with relatively complete lists of the species present, and have begun the process of assembling various datasets throughout the Arctic with the ultimate goal of establishing pan-Arctic patterns and trends over time (see Gradinger et al., 2010) for the taxonomic groups. The most comprehensive assessment in the Arctic is the Arctic Biodiversity Assessment (ABA), which includes chapters on marine mammals, birds, fishes, invertebrates, parasites, and ecosystems, contributed and reviewed by more than 100 scientists (Caff, 2013).

There are about 24 species of large unique vertebrates, such as the Polar Bear, Walrus, seals and several species of whales, found in the Arctic. As for seabirds, 64 species are recognized as breeding in the Arctic, and an even greater number of species is known to exploit its productivity seasonally (Archambault et al., 2010). Many of these air-breathing species are displaced southward during the winter's ice cover. As for fishes, nearly 250 species are known from the Arctic. About 30 of these divide their lives between the oceans and freshwater, and the rest are fully marine; the majority of these species are associated with the seafloor rather than living higher in the water column. Invertebrate diversity is higher and, unlike the vertebrates, invertebrates are typically studied in terms of communities rather than by species or higher taxonomic units. From functional and logistical perspectives, these communities are further divided by habitat, as this is how they are targeted during sampling: those associated with the sea ice, those within the water column (plankton) and those living on the seafloor (benthos). Of the functional groups of organisms considered thus far, with the exception of birds and mammals, species discovery continues within them all, especially now with the use of molecular tools for species identification (Gradinger et al., 2010). The Arctic is a mosaic of habitats across all its marine realms, within which information is very unequally collected between regions and over time. Habitat complexity, combined with the logistical challenges of sampling in the Arctic, and the generally limited interest in surveying the perceived low-diversity invertebrate fauna of the Arctic, have greatly impaired our ability to construct precise regional and temporal understanding of marine invertebrate diversity. Although changes have been noted in population size, abundance, growth, condition and behaviour of several marine mammals and fish, few changes for planktonic and benthic systems are documented. No comprehensive monitoring activities are conducted in the Central Arctic Ocean; oceanographic and ecosystem sampling has been occurring largely on an opportunistic basis, as part of national (e.g. Canadian) and international research programmes. Some efforts have been directed at developing directed systematic programmes for data collection, sometimes relying on community-based collaborations, but these are recent

developments and baseline data from the Canadian Arctic Ocean are very limited in their spatial and temporal extent.

Examples of these collaborations are the Arctic Council CBMP (Circumpolar Biodiversity Monitoring Program), the Russian-American Long-term Census of the Arctic (2004-12), which involves a partnership of several United States and Russian Federation institutions to create a baseline dataset in the Pacific gateway area of the Bering Strait and southern Chukchi Sea, and other bi-national collaborations (e.g. United States and Canada, Russian Federation and Norway). Recently, the United States Bureau of Ocean Energy Management (BOEM) initiated programmes in Arctic waters to provide estimates of abundance and species composition of marine fishes and invertebrates, as well as information on the macro- and microzooplankton communities and their oceanographic environment. In 2008, the oil and gas industry began new biological assessment programmes (Chukchi Sea Offshore Monitoring in Drilling Area: Chemical and Benthos) in the Chukchi Sea in response to the sale of leases for new offshore prospect areas (Fautin et al., 2010).

3.2 *Northern Hemisphere: focus on Canada*

Canada borders the Pacific, Arctic, and Atlantic Oceans; and its coastline of 243,791 km (16.2 per cent of the global coastline) exceeds all of Europe combined. At 2,687,667 km², Canada's territorial sea covers 14.3 per cent of the global total. The Census of Marine Life program (Archambault et al., 2010), in collaboration with the Canadian Healthy Oceans Network (CHONe) (Snelgrove et al., 2012), conducted an assessment of the status of knowledge on marine biodiversity in Canada's oceans which included four biogeographical provinces: the Canadian Arctic (including the sub-Arctic Hudson Bay System), Eastern Canada, St. Lawrence estuary and Gulf, and Western Canada (Pacific coast). The taxonomic assessment encompassed the status of knowledge on microbes, phytoplankton, macroalgae, zooplankton, benthic infauna, fishes, and marine mammals resulting in an estimate of between 15,988 and 61,148 taxa (including microbes), a number that is most likely to be an underestimate, as many poorly sampled taxa and regions still exist. This assessment noted that significant data gaps exist, that larger species (e.g., mammals and fishes) are better known than small species (e.g., microbes), and that knowledge of diversity is inversely related to both water depth and geographical remoteness. Thus, even for well-known groups, such as fishes, deep-water and Arctic environments continue to yield new species. The Eastern Canada waters are the best-sampled province of Canada.

The Census of Marine Life was very active in Canada and significantly helped advance knowledge of marine biodiversity. The Barcode of Life developed barcodes for many Canadian species, and the Future of Marine Animal Populations (FMAP) programme provided many new insights on trends in fisheries, global patterns in biodiversity, and movements of animals in the oceans. The Pacific Ocean Shelf Tracking (POST) project provided new insight into movements of Pacific salmon species, sturgeon, and other species along the North Pacific coastline. The Canadian Healthy Oceans Network

(CHONe) (Snelgrove et al., 2012), a five-year national research programme to establish biodiversity baselines in poorly sampled areas, grew out of the Census of Marine Life. Several other Census projects sampled in Canadian waters: include the Arctic Ocean Diversity (ArcOD) project, and the Natural Geography of Inshore Areas (NaGISA), and the Gulf of Maine Area (GoMA) project. The latter project assembled species lists for that region and worked closely with the Canadian scientists of the Ocean Biogeographic Information System (OBIS) program, which assembled extensive datasets produced by Fisheries and Oceans Canada over several decades.

Current monitoring programmes, largely by the Department of Fisheries and Oceans Canada (DFO), the lead agency responsible for monitoring Canada's three oceans (Atlantic, Pacific and Arctic) and freshwater habitats, will further improve knowledge of Canadian oceans. Many of DFO's monitoring activities were initiated to address operational requirements dealing with commercial exploitation of marine and freshwater populations, but over time many have evolved to provide assessments of the state of local ecosystems in the context of a consistent national approach. A general assessment of aquatic monitoring in Canada, conducted in 2005-2006 (Chadwick, 2006), provides an overview of the diversity of activities carried out by DFO and other agencies.

Most programmes that contribute to biodiversity assessments derive data from: (1) broad-scale regional multispecies bottom trawl surveys that provide information on the distribution and abundance of fish and invertebrate species, (2) oceanographic surveys that collect observations of phytoplankton and zooplankton abundance and taxonomic composition, and (3) single-species surveys that can yield knowledge for non-target species caught or observed during data collection. Most surveys are carried out by DFO, but in several instances, most importantly in the Pacific region, partner organizations contribute significantly, such as assessments of coral and sponge diversity distributions aided by academic and by non-governmental organizations (NGO) activities. Coverage varies greatly among aquatic environments.

Monitoring of the Atlantic and Pacific continental shelves and slopes is fairly extensive and generally conducted annually for focus areas. On the Pacific coast, Canada has maintained one of the longest – in duration – datasets that exist on ocean conditions, phytoplankton and zooplankton through the Line P/Station Papa programme. For other species groups, such as marine mammals, groundfish and salmon on the west coast, monitoring remains a DFO focus. Differences in the extent and intensity of survey activities in specific ecosystems within these two ocean areas will affect our ability to detect changes in biodiversity. For example, the coastal sea near Vancouver and the Fraser River salmon runs are the focus of sustained monitoring for many species; however, little information on the biodiversity of the northern west coast fjord exists. Furthermore, protocols for data collection, taxonomic resolution and expertise, and quality assurance vary greatly among survey types and location, which are also likely to significantly affect the estimation of Canadian marine biodiversity, particularly with respect to the occurrence of rare or difficult-to-identify species, including invasive species.

In all of Canada's oceans, information sources on habitat structure, invasive species, food web structure and interactions, species at risk, and any effects of cumulative anthropogenic impacts are limited. There are few systematic efforts to assess ecosystem health, particularly in near-shore and coastal areas, and data pertaining to pelagic species other than plankton are restricted in scope and coverage. Finally, almost all marine observations are collected from ships, yet the number of sea days declined by half between 1995 and 2005, while costs have doubled (Chadwick, 2006).

3.3 North Atlantic: The East Coast of the United States

The marine biodiversity of the United States is extensively documented; however, even the most complete taxonomic inventories are based on records scattered in space and time. The best-known taxa are those of commercial importance or large body sizes. Best-known areas are the shore and shallow waters. Measures of biodiversity other than species diversity, such as ecosystem and genetic diversity, are poorly documented. In the North-east Continental Shelf region, scientific sampling of coastal intertidal and shallow subtidal organisms extends back to the mid-1800s. Off-shore, early assessments in the late 1800s and early 1900s include those conducted by the *Fish Hawk*, the *Albatross*, and by Henry Bryant Bigelow.

In the last decade, the Gulf of Maine Area Program of the Census of Marine Life assessed this ecoregion, plus the southern and western Scotian Shelf, the continental slope to 2,000 m, and the western New England Seamounts. In the South-east Continental Shelf region, assessments began during the United States colonial period (seventeenth and eighteenth centuries). Early offshore studies focused on finding exploitable fish populations. In the late 1800s, exploratory surveys were aimed primarily at bottom-living organisms. Since the mid-twentieth century, the United States National Oceanic and Atmospheric Administration (NOAA) and its predecessor agencies (e.g., the Bureau of Commercial Fisheries) have explored habitats and their natural resources off the coast of the south-eastern United States. Beginning in the 1950s, several ships conducted exploratory fishing surveys using trawl nets; they found concentrations of snappers, groupers, and other economically valuable fishes, along with other significant fishery resources (drums, flatfishes, mullets, herrings, shrimps). Additional surveys using dredges, grabs, and other benthic samplers collected invertebrates and new species.

Valuable fish surveys have been carried out by the NOAA Marine Resources Monitoring, Assessment and Prediction (MARMAP) and Southeast Area Monitoring and Assessment Program (SEAMAP) monitoring programmes. Significant regional invertebrate surveys of the South Atlantic Bight (SAB) were conducted under the auspices of the Bureau of Land Management (BLM) and the Minerals Management Service (MMS). From the 1970s until now, surveys of the continental shelf and slope off North Carolina and in the tropical western North Atlantic have been made by the Duke University Marine Laboratory (DUML) and the Rosenstiel School of Marine and Atmospheric Sciences

(RSMAS) of the University of Miami, respectively. The RSMAS collections and archives (Marine Invertebrate Museum: <http://rsmas.miami.edu/divs/mbf/invert-museum.html>) document the biodiversity of the Atlantic and Gulf of Mexico's tropical and deep-sea species and include material from the Straits of Florida and the Florida Keys National Marine Sanctuary. Marine resource agencies of the individual states have also conducted faunal and fishery surveys within state waters, particularly within estuaries (Fautin et al., 2010).

3.4 North Atlantic: The Gulf of Mexico

The most recent survey of the Gulf of Mexico's biodiversity appeared in book form (Felder and Camp, 2009), and as an open-access online database for utilization by anyone, as well as for updating and expansion by taxonomists (see GulfBase at www.gulfbase.org/biogomx; Moretzsohn et al., 2011). Over 15,400 species are listed in the database, with full biological and zoogeographical information for each species.

Historically, environmental studies or assessments on the Gulf of Mexico's biota can be divided into four different periods: (1) Exploratory Period (1850-1939), (2) Local Coastal Study Period (1940-1959), (3) Multidisciplinary Investigation and Synthesis Period (1960-2009/2010), and (4) Ecosystem Focus Period (2009/2010-present). The initial period involved the exploratory work of early oceanographically equipped ships, such as the *Blake* and the *Albatross*, and coastal expeditions from northeastern United States universities and institution. During the second period, over a dozen marine laboratories were established around the shores of the Gulf of Mexico, and scientists at these facilities expanded our biodiversity knowledge in those early locations in the United States, Mexico, and Cuba. Recently, a dedicated issue of the journal *Gulf of Mexico Science* (Volume 28, 2010) mapped the current 35 laboratories around the Gulf and presented a history of 21 of them; many are still instrumental in biodiversity assessments. Important fisheries vessels, such as the *Alaska* and the *Oregon I and II*, also operated in this second period and expanded our knowledge of faunal distributions in the region. In addition, although not comprehensive, the first biotic inventory of species in the Gulf of Mexico was published by Galtsoff (1954).

The third period involved large-scale, multidisciplinary investigations and synthesis projects in selected regions, primarily in the United States and Mexico. In the United States during the early to mid-1960s, the Hourglass Cruises were among the first large-scale projects, focused on the biota of the West Florida Shelf, and funded by the state of Florida. The United States Department of the Interior, Bureau of Land Management, Minerals Management Service, and now the Bureau of Ocean Energy Management, funded decades of environmental studies, including biotic surveys, mainly related to the oil and gas industry and its impact in the northern Gulf of Mexico. These studies first focused on the continental shelves, but as the oil and gas industry began exploring and producing in deeper and deeper water down the continental slope, studies focused on that area and out onto the adjacent abyssal plain. Those reports can be found at: <http://www.data.boem.gov/>.

The fourth period marks its beginning with the publication of the comprehensive inventory of all Gulf of Mexico species (Felder and Camp, 2009; an affiliate Census of Marine Life project) and the Deepwater Horizon blowout and oil spill in 2010, including the establishment of the Gulf of Mexico Research Initiative funded by BP with 500 million United States dollars to study the Gulf and its ecosystems over the next 10 years (at 50 million dollars per year) (See Appendix 1-Gulf of Mexico: selection of the major assessments or surveys - the Gulf of Mexico).

Gaps in knowledge include selected taxa and selected geographic areas or depths within the Gulf of Mexico. Similar to most well-studied areas, the larger taxa are well known, but smaller ones, particularly meiofauna and microbiota (viruses, microbes, fungi, benthic nematodes and harpacticoid copepods, etc.), gelatinous plankton and other soft-bodied invertebrates (that often do not preserve well in non-targeted sampling), as well as parasitic groups, are little known. Biomass, ecology, trophic interactions and diseases are poorly known for most species. Geographically, still not well known are the abyssal plain in the deepest part of the Gulf, and selected areas in the southern Gulf, such as off the northern coast of Tamaulipas and the very southern coast of Veracruz off the San Andres Tuxtla Mountains.

3.5 *North Atlantic: The Caribbean*

Historically, knowledge of marine biodiversity for the Caribbean islands has resulted from inclusions within larger marine surveys and assessments funded by foreign institutions. For example, the Universities of Havana and Harvard (1938 to 1939) carried out a joint marine expedition which was the first such baseline information for the Cuban archipelago. Additionally, some territories have benefited from visiting research vessels (e.g., the 1969 RV *John Elliott Pillsbury* expedition to the Lesser Antilles). More recently, local institutions dedicated to marine research have been established in several islands, such as: The Oceanology Institute (Cuba), the Institute of Marine Affairs (Trinidad) and The Discovery Bay Marine Lab (Jamaica). The Association of Marine Laboratories of the Caribbean (AMLC) (<http://www.amlc-carib.org/>) is an umbrella organization (with over 30 institutions) which has been promoting collaborations in marine sciences since 1968. Other organizations supporting research initiatives in the region are the International Oceanographic Commission-Caribe (IOCARIBE), the Nature Conservancy (TNC)), and several universities (e.g., the University of the West Indies island campuses of Mona in Jamaica, Cavehill in Barbados, and St. Augustine in Trinidad and Tobago).

To date not a single comprehensive marine assessment has detailed the Caribbean island territories, although several projects have targeted certain ecosystems and taxonomic groups. One of the most successful research programmes to date (1993 to present) is the Caribbean Coastal Marine Productivity Program (CARICOMP), which covers islands throughout the Wider Caribbean (e.g., Barbados, Dominican Republic,

Jamaica, Puerto Rico (Mona Island) and Trinidad and Tobago) and has over 30 participating institutions. The project datasets include: percentage coral cover, sea urchin density, gorgonian density, seagrasses (growth, biomass and leaf area), mangrove forest structure and productivity, sea water temperature, salinity and clarity, daily maximum and minimum air temperature, and rainfall.

Furthermore, the Atlantic and Gulf Rapid Reef Assessment (AGRRA) Program is an international collaboration of scientists and managers aimed at determining the regional condition of reefs in the Western Atlantic and Gulf of Mexico and includes some Caribbean territories. Additionally, the Northern Caribbean and Atlantic node of the Global Coral Reef Monitoring Network (GCRMN) monitors coral reefs and their status in the Bahamas, Bermuda (United Kingdom), Cayman Islands (United Kingdom), Cuba, the Dominican Republic, Haiti, Jamaica and the Turks and Caicos Islands (United Kingdom). The Centre for Marine Sciences (CMS) at the University of the West Indies (UWI), at Mona, Jamaica, is the repository for these three databases (CARICOMP, AGRRA, GCRMN). Reef Check is another coral programme and is active in: Anguilla (United Kingdom), Antigua and Barbuda, Bahamas, Barbados, Belize, Dominica, Grenada, Haiti, Jamaica, Montserrat (United Kingdom), St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, and Trinidad and Tobago.

The Caribbean Sea Ecosystem Assessment (CARSEA) was a sub-global assessment (2005 to 2008) out of the global Millennium Ecosystem Assessment (MEA, 2001 to 2005) which made a major contribution to Caribbean biodiversity knowledge, and provided analytical status reports, including trends in some populations such as fish and coral reefs. The Census of Marine Life resulted in a detailed review of the known marine biodiversity of several Caribbean islands, including Bermuda (United Kingdom), , Cuba, the Dominican Republic, Jamaica and Puerto Rico (United States) and of the marine biodiversity along the Caribbean coasts of Colombia, Costa Rica, Mexico and Venezuela (Miloslavich and Klein, 2005). The nearshore (NaGISA) project followed shortly thereafter, with biodiversity surveys in Colombia, Cuba, Trinidad and Tobago, and Venezuela. This assessment examined patterns of biodiversity at both global and local scales on rocky shores and seagrass beds and made a major contribution to marine biodiversity (Miloslavich et al., 2010).

Overall, within the larger assessments (CARICOMP, CARSEA, CoML), certain ecosystems (mangroves, coral reefs, seagrass beds and rocky shores) have been studied in detail and certain marine taxonomic groups (marine mammals, turtles, seabirds, fish, corals, sponges) have also been comprehensively reviewed/assessed by local researchers, scientists and post-graduate students. Macrobenthic organisms for both Trinidad and Tobago and Jamaica, and plankton (for Jamaica) have been well documented. These important baseline data were improved by later surveys by the Institute of Marine Affairs in Jamaica (IMA) during the period 1980 to 1992.

Despite these efforts, there are still many gaps in our knowledge of Caribbean biodiversity (e.g. offshore and deep regions, small sized taxonomic groups) (Miloslavich et al., 2010). To fill these gaps and build regional capacity, almost all Caribbean

countries have strengthened their environmental institutions (e.g., Coastal Zone Management Institute-Belize; Coastal Zone Management Authority-Barbados; Darwin Initiative by the Smithsonian Tropical Research Institute) and administrative capacities (e.g., the Environmental Management Authority-Trinidad and Tobago), to integrate environmental considerations into physical planning. Another initiative that has improved capacity building and aimed towards maintaining functional and structural integrity and biodiversity in this region is the Caribbean Large Marine Ecosystem Project (CLME). While not a monitoring programme, the CLME Program has one pilot project on Reef Biodiversity and Reef Fisheries which implemented the ecosystem-based approach for the conservation and effective management of coral reef ecosystems and associated resources.

3.6 *North Atlantic: Oceans around Europe*

There is early evidence of European marine biota assessments from the 3rd century B.C., but formal scientific studies did not begin until the 18th century in the Mediterranean region and early 19th century throughout the remainder of Europe (Coll et al. 2010, Ojaveer et al., 2010). For several taxa these early works provide historical baselines against which to compare contemporary biodiversity data.

In the European Atlantic, as mentioned earlier in the plankton section, the longest time-series sets exist for planktonic organisms. Regarding benthic organisms, in shelf seas, such as the North and Baltic Seas, benthic survey and monitoring programmes have been in place. One of the priority research areas, directly linked to provision of management advice, in European seas has been commercial fish and fisheries. The related surveys include egg and larval fish surveys, young fish surveys, experimental bottom trawl surveys and, more recent hydro-acoustic surveys. Some of these data-sets date back to before the 1950s. However, information on non-commercial fish is scarce and incomparable and should be considered as a major drawback in drawing conclusions about the spatio-temporal patterns and dynamics of fish communities. A representative overview of the status and trends of non-indigenous species in European waters is assembled in the database “Information system on aquatic non-indigenous and cryptogenic species in Europe”, AquaNIS.

In the North-East Atlantic, the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR, formerly the Oslo-Paris Convention) established in 1972, is aimed towards the conservation of the marine environment and its resources. As such, OSPAR has pioneered ways of ensuring monitoring and assessment of the quality status of the seas, including the implementation of a Biodiversity and Ecosystem Strategy under the coordination of the Joint Assessment and Monitoring Program (JAMP).

3.7 North Pacific: focus on the West Coast of the United States

3.7.1 The Gulf of Alaska

There have been many scientific expeditions to the Gulf of Alaska over the years since early times and a historical review of scientific exploration of the North Pacific Ocean from 1500 to 2000 is available. Early explorations were carried out mostly for mapping and species identification (i.e. fishes, birds, and invertebrates). Marine survey expeditions in the late 1800s include the United States steamer *Tuscarora* in the Aleutian Trench, the *Albatross*, and the Harriman Alaska Expedition from Seattle through Prince William Sound, out to the Aleutians, and north along the Russian Federation coast of the Bering Sea. In the 1950s, major expeditions were carried out by NORPAC (North Pacific), the Japanese research vessel *Oshoro Maru*, the University of Washington's *Brown Bear*, the Russian Federation research vessel *Vityaz*, the Bering Sea Commercial Research Expedition, and the Pacific Research Institute of Fisheries and Oceanography (TINRO). Recent survey programmes are funded by MMS and NOAA. The MMS Outer Continental Shelf Environmental Assessment Program (OCSEAP) began in 1974 and is still active. The bottom trawl surveys run by NOAA collect information on fishes and many species from the Bering Sea, the Aleutians and Gulf of Alaska to support fishery management decisions by the North Pacific Fishery Management Council and the United States Secretary of Commerce. Biodiversity information has also been collected by the *Exxon Valdez* Oil Spill Trustee Council in Prince William Sound, continuous plankton recorder surveys across the North Pacific, Seward Line zooplankton collections in the Gulf of Alaska, and Hokkaido University's annual training cruises on the *Oshoro Maru* to the Bering Sea and Strait and, less frequently, to the Chukchi Sea. More recently, the NOAA Office of Ocean Exploration supported cruises (2002-05) to study biodiversity implementing the use of ROVs.

Large-scale research programmes off Alaska (see, e.g., the joint National Science Foundation–North Pacific Research Board Bering Sea study at <http://bsierp.nprb.org>) contribute to broader knowledge of biodiversity, and continue adding to the many efforts over the past 40 years to enumerate species from the coastal rocky headlands to the deep ocean and even in sea ice. However, no species inventory of all realms exists for any region of Alaska. Important databases containing biodiversity information are listed in Fautin et al. (2010) and efforts are underway to compile data in databases (e.g., Alaska Resources Library and Information Services - ARLIS; the *Exxon Valdez* Oil Spill Trustee Council - EVOSTC).

3.7.2 The California Current ecosystem:

Early surveys in this region began in the late 1700s and 1800s by European explorers, including Cook, La Perouse, Vancouver, and Bodega y Quadra. In the 1800s, United States naval expeditions collected information on fishes and whales. In the 1900s, marine research laboratories were established (e.g., Hopkins Seaside Laboratory in Monterey, California) which today form the Monterey Bay Crescent Ocean Research Consortium. Today, 40-50 marine research facilities operate in the region under the umbrella of the Western Association of Marine Laboratories. At present, many of the

available long-term data are a product of fishery management efforts, mostly funded by NOAA. Biodiversity databases of this region are listed in Fautin et al. (2010). Two major assessments in this region are the California Current Ecosystem Long Term Ecological Research (CCE LTER) and the California Cooperative Oceanic Fisheries Investigations programme (CALCOFI), both focused on the pelagic realm. The CalCOFI programme is a 60+ year survey including zooplankton with strong relations to biodiversity and a world-recognized data base allowing analysis of temporal trends (Kang and Ohman, 2014).

3.7.3 *Insular Pacific–Hawaiian Large Marine Ecosystem:*

Initial surveys of the Hawaiian Islands began in the early 1800s by French, Russian, and United States expeditions. The first plankton samples were taken by the *Challenger* in mid-1875, while major collections from Hawaii were initiated by the *Albatross* Expedition in the early 1900s. Between 1923 and 1924, four trips were made with the *Tanager* to survey 13 Hawaiian Islands, Johnston Atoll and Wake Island. Results from the *Tanager* expedition were published in *Marine Zoology of Tropical Central Pacific*, and included crustaceans, echinoderms, polychaetes, and foraminiferans. Between July and September 1930, an expedition led by P.S. Galtsoff to Pearl and Hermes, surveyed the abundance of pearl oysters for potential commercial use, and also noted the corals, algae, sponges, molluscs, crustaceans, and echinoderms.

Since these early cruises, conducting inventories of the biota of Hawaii has largely been the responsibility of the Bishop Museum, which at present has been designated the Hawaii Biological Survey (HBS). Surveys have occurred in targeted sites in the main Hawaiian islands, such as Kaneohe Bay and Pearl Harbor on the island of Oahu, and waters around the island of Kahoolawe.

Since 1995, surveys have also covered Midway Atoll, French Frigate Shoals, and Johnston Atoll. Electronic datasets for Hawaiian marine biodiversity include: <http://hbs.bishopmuseum.org/> (Hawaii Biological Survey); <http://cramp.wcc.hawaii.edu/> (Reef Assessment and Monitoring Program); http://www.nbio.gov/portal/community/Communities/Geographic_Perspectives/Pacific_Basin/ (National Biological Information Infrastructure (NBII), Pacific Basin Information Node); and [http://www.nbio.gov/portal/community/Communities/Habitats/Marine/Marine_Data_\(OBIS-USA\)/](http://www.nbio.gov/portal/community/Communities/Habitats/Marine/Marine_Data_(OBIS-USA)/). Intensive biological inventories have been carried out on fishes, stony corals, crustaceans, and molluscs (Fautin et al., 2010).

3.8 *North Pacific: focus on Japan*

In Japan, nationwide censuses of biodiversity of coastal areas, such as tidal flats, coral reefs, seagrass and algal beds, were conducted by the Ministry of the Environment, and showed long-term decline of these important habitats during the 1970s-1990s. However, the survey frequency was insufficient to identify the causal mechanisms of changes in relation to various environmental factors. Since 2002, the Ministry started a new type of monitoring programme, called "Monitoring Sites 1000" which aims to monitor the 1000

most important ecosystems in Japan over the whole 21st century. In this programme, ca. 50 coastal sites, including tidal flats, rocky intertidal shores, seagrass beds, algal beds and coral reefs are being monitored annually over the long term. These data will be utilized for various purposes, such as the prediction of coastal ecosystem response to global climate changes and other more local factors, as well as the impact assessment of the catastrophic disturbance by the 2011 earthquake and tsunami.

However, the number of sites is too small to set out in detail the changes in the coastal areas of the entire Japanese coast. In the meantime, local prefectural governments, fisheries agencies and certain NGOs have been conducting assessments of local coastal habitats of their areas, although the systems for sharing the information gathered are not well established at present. Certain ongoing network activities, such as the Japan Biodiversity Observation Network (JBON) and the Japan Long-term Ecological Research Network (JaLTER), are expected to collect this scattered information for use in developing integrated analyses of coastal ecosystem changes (Fujikura et al., 2010) (see Appendix 1-Japan for a list of assessments).

3.9 North Pacific: focus on China

The marine biological investigations in China started late. Until the early twentieth century, only limited areas had been explored and scattered taxonomic groups had been collected and researched. Additionally, due to the lack of special research institutes and taxonomists, many precious samples were lost.

From 1919 to 1949, some independent investigations and research on marine biological work in China were conducted. This period saw the real beginning of marine biological research in the country; the first qualitative benthic trawling investigation was launched in this time. But research conditions were very precarious and no research vessels for marine or fisheries science existed; therefore, surveys were relatively limited. During this period, research mainly focused on the coastal areas of Qingdao, Yantai, Xiamen, Beidaihe and Hainan Island.

Since the establishment of the People's Republic of China in 1949, many marine research institutions were set up gradually (e.g. Chinese Academy of Sciences - Institute of Oceanology (IOCAS) and South China Sea Institute of Oceanology (SCSIOCAS), State Oceanographic Administration (SOA), Ocean University of China (OUC), Chinese Academy of Fishery Sciences, etc.). Comprehensive oceanographic surveys were carried out from the 1950s to the 1980s. The National Comprehensive Oceanographic Survey (1958-1960; the First National Marine Census) was the first large-scale national comprehensive marine survey with participation of over 60 organizations and more than 600 researchers, which covered most coastal areas of the China seas north to the Taiwan Strait and most parts of the northern South China Sea. The biological investigation of this survey included assessments of plankton, benthos and nekton. More than 200,000 biological specimens were collected.

Other large-scale comprehensive marine surveys include the National Coastal Zone and Beach Resources Comprehensive Survey (1981-1987) and the First National Island Resources Comprehensive Survey (1988 -1996). These two surveys covered over 50,000 km², and involved microbial, planktonic, benthic and nektonic community investigations. These surveys investigated the coastal and island natural environments from China, and comprehensively evaluated the quantity, quality and distribution of biological resources. By the late 1980s, most of the waters under the jurisdiction of China had been investigated, and the diversity, distribution and utilization of the main marine biological species were roughly identified.

From the 1990s to date, large-scale comprehensive marine surveys include: the Continental Shelf Environment and Living Resources Survey (1997-2000), the National Offshore Comprehensive Oceanographic Survey and Evaluation (2004-2010), also referred to as the Second National Marine Census, and the ongoing Second National Island Resources Comprehensive Survey. These surveys were very intensive and thorough, providing supplemental data to the earlier efforts.

In the past 20 years, more regional investigations, including assessments in Bohai Gulf, Liaodong Bay, Jiaozhou Bay, Changjiang Estuary, Dayawan Bay, Quanzhou Bay, Hainan Island, and some islands in the South China Sea have been performed, with continued study in several regions. More studies were focused on particularly diverse habitats, such as coral reefs, mangrove forests and seagrass beds. Oceanographic exploration is reaching further into areas adjacent to China's seas, including in the West Pacific Ocean, Indian Ocean, even the North and South Poles, as well as cold seeps and seamounts in the deep sea of South China Sea.

Although significant advances have been made in marine biodiversity research in China since the 1950s, much insufficiency still remains. First, the marine biological specimen collection and biodiversity research is considered inadequate, especially from coral reefs, the deep sea and other special habitats. Second, the current investigations are considered as lacking systematic and thorough data publication. Third, the phylogenetic and biogeographic studies on marine living organisms are insufficient. Last, supervision and conservation are weak, and many species are critically endangered (Liu, 2013) (see Appendix 1-China, for a list of assessments).

3.10 Indian Ocean: focus on India

The two major institutions concerned with surveys and inventories of the fauna and flora in India are the Zoological Survey of India and the Botanical Survey of India, along with other research organizations, such as the Central Marine Fisheries Research Institute and the National Institute of Oceanography.

The published literature on coastal and marine biodiversity of India comprises an inventory indicating that 17,795 species of faunal and floral communities were reported from seas around India (see Appendix 1-Species diversity India). The taxonomy of many of the minor groups, particularly invertebrates (especially sponges, octocorals,

ctenophores, tunicates, polychaetes and other worms, as well as small size invertebrates) remain a challenge to specialists; as a result these taxa continue to be inadequately known from Indian seas. However, considerable knowledge on the taxonomy of groups, such as seaweeds, seagrasses, mangroves, scleractinian corals, crustaceans, molluscs, echinoderms, fishes, reptiles and marine mammals, is available in India.

Most of the marine biodiversity data come from surveys that sample up to 200 meters. There are large data gaps for smaller taxa and for large parts of the shelf and deep sea ecosystems, including seamounts (Wafar et al., 2011). The data provided in this paper warrant continued taxonomic research on the least-studied and unknown groups, in light of current threats to marine biodiversity. The full extent of biodiversity in any of the world's oceans may never be known, and the rate at which our understanding is increasing (Keesing and Irvine, 2005) is likely to be lowest in Indian seas. The impacts of climate change will alter coastal marine ecosystems, affecting the range of species and their ecology at a rate faster than it is possible to record their presence and abundance (Keesing and Irvine, 2005). In conclusion, it is evident that comprehensive taxonomic coverage of the marine biota of the entire region remains a monumental task, beyond the capacity of existing local taxonomic expertise.

Thus, to gain an appreciable knowledge on the patterns of diversity in the region, it will be necessary to identify indicator species to assess responses to unpredictable climate change. It would be quite appropriate to plan systematic studies rather than continue the present system of haphazard and opportunistic description of new species as and when they are discovered.

Within the largest Indian Ocean basin, the International Indian Ocean Expedition (IIOE) was held during years 1962-1965. This expedition was one of the greatest international, interdisciplinary oceanographic coordinated research efforts to explore the Indian Ocean in almost all disciplines in the marine sciences. The culmination of IIOE led to birth of the National Institute of Oceanography at Goa, the first regional institute for oceanographic research. At present, the plan for a second International Indian Ocean Expedition (IIOE2) has been drafted by the Science Council for Oceanic Research (SCOR) and will include more biological aspects than the first, particularly in marine biodiversity. The need for these expeditions as well as other continued studies are of overall importance in a region recognized by having growing concerns on food security, biodiversity loss, coastal erosion and pollution, along with a pressing need of conservation for tourism and sustainable fisheries.

3.11 Sub-Saharan Africa

Along the coastline of Sub-Saharan Africa, states of knowledge of marine biodiversity vary dramatically between the east, southern and west coasts of Africa. The biota of the east coast is moderately known. A general field guide to marine life in the region exists and two reviews have attempted to tabulate and assess states of knowledge of regional

marine biodiversity. However, this listing is far from complete. Some well-known taxa, such as reptiles, birds and mammals, are simply omitted from the tabulation. Other larger and/or more economically valuable taxa, such as seaweeds, flowering plants, fishes, corals, larger molluscs and crustaceans, etc., are probably fairly accurately represented.

However, many smaller and difficult-to-identify taxa are not included in the lists at all (for example, Nematoda, Copepoda and Ostracoda) or are likely to be severely under-represented, and probably less than half of the actual numbers of marine species present in the region have been described. Notable regional differences in sampling effort are found: Kenya, United Republic of Tanzania and southern Mozambique are the best-sampled regions, and northern Mozambique and especially Somalia are the least studied. In all regions, sampling effort declines rapidly with depth and distance from the coast; the deeper continental slope and abyssal habitats are almost completely unexplored. Regional taxonomic capacity is very limited and adequate marine collections in regional museums are lacking.

The marine biota of South Africa is by far the best known on the continent. The region has a relatively strong history of marine taxonomic research and a reasonably comprehensive and well-curated museum collection network, totalling some 291,000 marine records. South Africa has more than a dozen institutions with a strong focus in marine science (e.g. South African Institute of Aquatic Biodiversity or SAIAB, formerly the JLB Smith Institute of Ichthyology), with the largest concentration of marine scientists found in the Cape Town region.

Several regional guides to marine life, such as Branch et al. (2010), list more specialized taxonomic monographs. The regional data centre, AfrOBIS, houses some 3.2 million records of more than 23,000 species. These are derived from the wider African region, although the vast majority of data points originate from within South Africa. The total number of recorded marine species stands at 12,914 and these are tabulated by taxonomic group by Griffiths et al. (2010), who also list taxonomic resources and experts for the region. Many groups, particularly of smaller invertebrates, still remain poorly studied, however. In terms of regional coverage, shallow waters have been relatively well sampled, but sampling effort declined dramatically with increasing depth: 99 per cent of all samples have been taken in depths shallower than 1000 m. The 75 per cent of the EEZ that lies deeper than 1,000 m thus remains extremely poorly explored and is a priority for future research.

The marine biota of West Africa is poorly known. No regional marine guide exists and no comparative analyses of regional marine biodiversity have been compiled. Some reports purport to list the biodiversity for various individual countries in the region, but these are clearly superficial and fail to adequately reflect the diversity of smaller taxa. For example, in the Namibian EEZ, only 1,053 species are documented, of which more than half are fishes. This amounts to less than 10 per cent of the total known from South Africa, where fish comprise less than 20 per cent of the recorded taxa, indicating that the Namibian estimate is strongly biased towards larger, more conspicuous taxa. Similar

biases are evident in other national estimates, which appear to radically underestimate smaller, less conspicuous components of the biota and to concentrate on fishes and other 'target species'. This entire region probably remains amongst the least explored of coastal marine areas and a pressing need remains for taxonomic study of most invertebrate groups in the region. As with other regions sampling effort in waters deeper than 1,000 m is particularly lacking (see Appendix 1-Africa for a summary of assessments).

3.12 *South Pacific: focus on Australia and New Zealand*

3.12.1 *Australia*

Although Australia has the world's third largest EEZ, extending more than 5,000 km from the tropics (9°S) to temperate latitudes (47°S), it has a comparatively small marine survey capacity. At the same time, Australia has been very active in progressing marine conservation planning (called Marine Bioregional Planning), including the identification of a network of representative marine reserves covering 36.4 per cent of the EEZ. The need to support marine bioregional planning encouraged researchers to recover, validate and make accessible older surveys going back to the 1950s. Some of the most widespread data are associated with 4,000 exploratory demersal trawls by Russian Federation fishing vessels for the period 1965-78. Cooperation with scientists in Vladivostok, in the Russian Federation, and in Australia enabled data for earlier surveys to be made accessible and, where necessary to be aligned with modern taxonomy.

Aboriginal people accumulated much knowledge of Australia's flora, fauna, and ecological systems, including those of its "sea country," over the last 40,000 to 60,000 years, but much of this knowledge and understanding remains cryptic (Butler et al., 2010). European scientific study began with the first scientifically staffed voyages of discovery, notably those of James Cook in 1770, Nicolas Baudin in 1801–03, and Matthew Flinders in 1802. Charles Darwin visited Australia in the *Beagle* in 1836. The voyage of HMS *Challenger*, 1872–76, included Australian samples in its global investigation of the deep sea, and its reports are a basis of many disciplines. Soon after the British established the colony of New South Wales in 1788, scientific societies and natural history museums entered an active period of research. Discovery in the sea was more difficult and more limited than on land, but there was much activity during the twentieth century.

The taxonomy and descriptive ecology of organisms on accessible shores were an early focus, which has developed into a strong tradition of experimental ecology on seashores and in shallow water, as well as a determined effort to produce identification guides (Butler et al., 2010). The study of plankton and of benthopelagic coupling is less well developed than the study of benthos in Australia. Publications on phytoplankton have been available in Australia since the 1930s, but species lists are available only for limited locations. Research on zooplankton ecology has increased recently and several transects are now surveyed regularly with the Continuous Plankton Recorder. Mesopelagic

organisms are being assessed on several cross-Tasman transects from commercial vessels using standardized mid-water acoustic survey techniques supported by periodic mid-water trawls. These two standardized approaches are part of the Integrated Marine Observing System (IMOS; www.imos.org.au).

The diversity of sources from which Australian marine biodiversity data are obtained means that there are few repeat surveys – typically each survey has set out to answer a particular research question with scant regard to long-term comparison. A notable exception is the Australian Institute of Marine Science (AIMS) Long-Term Monitoring Program; it recently analyzed 2,258 standardized surveys from 214 different reefs between 1985 and 2012 and showed that coral cover had declined from 28.0 per cent to 13.8 per cent (0.53 per cent y⁻¹). This programme, together with the much newer IMOS, are the only long-term sustained monitoring programmes in Australian waters, although individual researchers have conducted repeat surveys using standardized sampling techniques for individual research projects, or have collated a variety of historical data sources to answer particular questions. Australian scientists recognize the need to develop longer time-series of survey data to support national State of the Environment reporting and to measure the effectiveness of the marine reserve network. This will require increased capabilities and capacity for biological sampling, which need to be brought to a similar level of standardization, replication, sustainability, interpretation and communication, as has been achieved by physical oceanographers.

Beginning in the first half of the twentieth century, energetic research was targeted at fisheries by Australian state agencies and by CSIRO's Division of Fisheries and its predecessors (Mawson et al., 1988). Although searching for commercial prospects, this work collected many non-commercial fish and invertebrates that were lodged in museums throughout the country, including the Australian National Fish Collection at CSIRO Marine and Atmospheric Research (CMAR). These fish collections have recently provided the most comprehensive and useful biological dataset for bioregionalization of Australian waters. In the 1960s, a period of intensive environmental research began, targeting in particular, bays, estuaries, and continental shelf near major capital cities (Wilson, 1996).

More recent work has explored deeper waters, with interests in exploration, the conservation of biodiversity and research on sustainable fisheries, more recently as part of the Australian Government's National Environmental Research Program Marine Biodiversity Hub (and predecessors), set up to provide the scientific information to support government policy and decision-making. Thus, museums are building important collections of Australian specimens from depths as great as 2,000 m and, in restricted parts of the shelf and slope, quite comprehensive faunal collections. An important component of the taxonomists' work, besides describing the 30-50 per cent of species that are new to science found on each survey, has been to provide regionally consistent descriptions of species so that broader bioregional patterns can be established. Although this has been available for fish species for many years, supported by genetic barcodes, it has only recently been possible for some invertebrate taxa.

With the declaration of Australia's Commonwealth Marine Reserve network (<http://www.environment.gov.au/marinereserves/>), survey emphasis is shifting from discovery to monitoring (or establishing the first quantitative baseline). Non-destructive sampling approaches, including autonomous underwater vehicles (e.g., www.imos.org.au/auv) and possibly genetic approaches, will be important additions to what will remain Australia's most prevalent deepwater activity – commercial fisheries which will continue outside the marine reserve network and inside the network in multiple-use areas, collecting data from their fishing operations and additionally, through cooperation with scientists, to routinely collect scientific information. In shallower waters it is likely that standardized citizen science will become increasingly valued.

3.12.2 New Zealand

The New Zealand's EEZ is one of the largest in the world. Despite important exploration efforts begun more than 200 years ago by James Cook followed by Louis Duperry and Dumont D'Urvillefor, Charles Darwin, the Challenger, and continued at present, much of this region remains unexplored biologically, especially at depths beyond 2,000 m. The major oceanographic data repository is the National Institute of Water and Atmospheric Research (NIWA), which is also data manager and custodian for fisheries research data owned by the Ministry of Fisheries. Museum collections in New Zealand hold more than 800,000 registered lots representing several million specimens. During the past decade, 220 taxonomic specialists (85 marine) from 18 countries engaged in the review of New Zealand's entire biodiversity, which ended in a major three-volume publication (Gordon, 2009). Current marine biodiversity in New Zealand surpasses the 17,000 species, and a list of all described New Zealand marine Animalia is available through OBIS (Gordon et al., 2010).

Multiple surveys (2000-2008) have been commissioned by the Ministry of Agriculture and Forestry Biosecurity New Zealand (MAFBNZ) in ports to detect alien species which have generated baseline information of species composition in these areas. At present, marine research (including marine biodiversity assessments) has a significant momentum in New Zealand with funding from the Ministry of Fisheries, the Foundation of Research, Science and Technology, the Ministry of Agriculture and Forestry, Biosecurity New Zealand, and the Universities Performance Based Research Fund. The Ocean Survey 20/20 programme(administered by Land Information New Zealand), could perhaps be noted as one of the most significant biodiversity assessments carrying out biodiversity sampling and habitat mapping in the New Zealand EEZ and Ross Sea/Southern Ocean on a yearly basis. Large areas have been surveyed on the Chatham Rise, Challenger Plateau (down to about 1,200 m), the Ross Sea and Southern Ocean (down to about 3,500 m), and currently in a large area of the northeastern North Island shelf out to 200 m. Data from many of these surveys is still being processed (Gordon et al., 2010).

3.13 Oceans around South America

The first studies of the South American coastal biota were carried out during a series of expeditions by European and North American researchers in the late 1700s and the first half of the 1800s, with naturalists Alcide d'Orbigny, Alexander Von Humboldt, Aimé Bonpland, and Charles Darwin, among others. In the late 1800s, several other important oceanographic expeditions, including the HMS *Challenger*, collected samples along the coasts of Ecuador, Peru, Chile, Argentina, Uruguay, and Brazil. In the 1900s, the Deutsche Südpolar Expeditions in 1901–03, the Swedish Lund University expedition to Chile in 1948–49, the Royal Society Expedition to Southern Chile, the Soviet Antarctic Expedition in 1955–58, and the Calypso campaigns in 1961–62 were among the most significant European expeditions to South America. Other important campaigns during the second half of the twentieth century which increased the knowledge of marine biodiversity and strengthened the local research capacities were carried out by the R/V *Academik Knipovich* (1967), the R/V *Almirante Saldanha* (1966), the R/V *Atlantis II*, (1971), the R/V *El Austral* (1966–67), the R/V *Vema* (1962), and the R/V *Walther Herwig* (1966–71). At present, the oceanographic vessel *Polarstern* from the Alfred Wegener Institute (Germany) has been carrying out exploration voyages to the southern regions of the continent and the Southern Ocean for more than 20 years.

In the northern latitudes of the continent, the Tropical Eastern Pacific (TEP) Biogeographic Region has a rich history of oceanographic and biological explorations dating back to the voyage of Charles Darwin to the Galápagos Islands aboard the HMS *Beagle* in 1835 and the Eastern Pacific Expedition of the United States National Museum of Natural History in 1904 aboard the United States Fish Commission steamer *Albatross*. A series of research cruises and expeditions organized by North American institutions in the first half of the twentieth century contributed greatly to the discovery and knowledge of the marine fauna and flora existing in the rich area between the low-tide mark and 200 m of depth in the Panama Bight, including Panama, Colombia, and Ecuador (e.g., the *Saint George* to Gorgona Island in 1927, the Allan Hancock cruises aboard the *Velero III* and *IV* vessels (1931–1941), the Askoy Expedition of the American Museum of Natural History in 1941). Taxonomic and ecological studies have been carried out in the last three decades in Costa Rica, Panama, Colombia, and Ecuador, mostly in the Gulf of Nicoya, the Bay of Panama, the Pearl Islands, the Bay of Buenaventura, Gorgona Island, and the Gulf of Guayaquil.

Important collections or libraries of regional marine fauna are maintained by the Los Angeles County Museum, the Scripps Institution of Oceanography at La Jolla, California, the California Academy of Sciences in San Francisco, and the Smithsonian Tropical Research Institute (STRI) in Panama City.

In the Tropical Western Atlantic (TWA), the natural history of Guyana (formerly British Guiana) was described by early explorers Sir Walter Raleigh (circa 1600) and Charles Waterton (early 1800s), who reported his discoveries in the book “Waterton's Wanderings in South America”. In French Guiana, the first studies were carried out after World War II, for fish inventories and later, in the 1950s, on benthic (mostly shrimps)

and demersal continental shelf fauna, from 15 to 100 m depth. The Venezuelan Atlantic Front was until recently almost completely unexplored, and the little information available concerned commercially valuable species of fish and shrimp.

In the southern part of the continent, the local and regional academic community also had important historical representatives and in the 1900s, research on coastal biodiversity received a strong stimulus due to the immigration of many European scientists who contributed to knowledge and capacity-building mainly through their involvement in local universities and natural science museums. Although a few research institutions were established in the region early in the twentieth century, such as the Smithsonian Tropical Research Institute (STRI) in Panama (1923), the most important stimulus to regional, autochthonous marine science was given by the establishment of several marine research institutions, mostly in the 1950s and 1960s. These institutions changed the way that marine science was done by incorporating time series of the environmental variables and their effect on biodiversity into the traditional taxonomic studies.

In the 1960s, the Food and Agriculture Organization of the United Nations began to develop projects giving an impetus to fisheries, especially in the southwest Pacific, an upwelling zone of extraordinary productivity that was responsible for 20 per cent of the world's fisheries by the end of that decade. In the 1980s and 1990s, centres for marine biodiversity research were created along the coasts of several countries, especially Brazil, Argentina, and Chile. The natural history museums in South America have been fundamental to preserving the regional marine biodiversity patrimony, both in collections and in the literature, and are considered to be taxonomically indispensable.

Some of the most relevant museums are the Museo de La Plata and the Museo Argentino de Ciencias Naturales (Argentina), the Museo de Historia Natural (Quinta Normal) in Chile, the Museo Dámaso Larrañaga and the Museo de Historia Natural in Uruguay, and the Museo de Boa Vista (Brazil). Other important collections are held at research institutions such as the STRI in Panama, the Instituto del Mar del Perú (IMARPE) in Peru, the Instituto de Investigaciones Marinas y Costeras (INVEMAR) in Colombia, and at universities.

Today, South America benefits greatly from regional cooperation. One example of cooperation was the Census of Marine Life that incorporated the region into several of its field projects (e.g., Shore Areas, Antarctic Life, Continental Margins, Marine Microbes (ICoMM), and the Mid-Atlantic Ridge Ecosystem (MAR-ECO) projects), which all contributed greatly to increasing the knowledge of marine biodiversity in the region. South America also has contributed nearly 300,000 records to OBIS from almost 7,000 species through its regional node.

At present, some of the main marine biodiversity assessments carried out in the region are:

- (1) SARCE: South American Research Group in Coastal Ecosystems (regional); since 2010. Aimed to study biodiversity and ecosystem function in the intertidal zone of rocky shores: <http://sarce.cbm.usb.ve/>;
- (2) Pampa Azul: South Atlantic (Argentina, approved in 2014). Aimed to carry out research for conservation purposes along with technology development and outreach;
- (3) SIMAC: Sistema Nacional de Monitoreo de Arrecifes Coralinos en Colombia; since 1998. Yearly sampling to monitor state of coral reefs. Taxa monitored include corals, macroalgae, invertebrates, and fish;
- (4) IMARPE (Instituto del Mar del Perú) and Universidad Nacional Mayor de San Marcos have initiated at least four projects characterizing marine biodiversity in several areas along the Peruvian coasts since 2009/2010 focused on benthic groups.
- (5) The Colombian National Authority for Aquaculture and Fisheries (AUNAP) in conjunction with INVEMAR carry out scientific research programmes to evaluate the Colombian potential to take advantage of new marine fishery resources such as tuna, dolphin fish, billfish, snappers, groupers and other fish of high commercial importance.

The objective of these programmes is to establish the current status of these resources in order to take management measures to promote the extraction of unconventional resources and discourage fishing pressure on those resources that are over-exploited. These studies provide not only information on highly important commercial species, but also a characterization on the status of marine biodiversity in the exclusive economic zone of Colombia.

3.14 *The Southern Ocean*

Whilst the economic exploitation of Antarctica's marine resources dates back to the 18th century, scientific research on its marine ecosystems only began in the mid-19th century. The HMS *Challenger*, the *Belgica* and the *Discovery* Investigations were among the first to undertake systematic sampling of the marine biology in the region. Taxonomic studies from these early expeditions provide the foundations of modern taxonomy in the Southern Ocean. Advances in technology, such as SCUBA diving, ice-capable research vessels and underwater imagery from remotely operated vehicles, have heralded a new era for marine ecological work in polar regions. Together with the recognition by the Scientific Committee on Antarctic Research (SCAR) and some national agencies of the importance of fundamental taxonomy, the rate of discovery and description of new species in the Southern Ocean has increased significantly.

In the framework of the Census of Marine Life a Decade of Discovery, life in the world's oceans has been investigated and questions about the known, the unknown and the unknowable have kept marine researchers busy. Many resources were made available for future research within the CoML community, but also for the public and policy-

makers. One of the flagship projects was the five-year Census of Antarctic Marine Life (CAML), which investigated the distribution and abundance of Antarctica's marine biodiversity, how it is affected by climate change, and how change will alter the nature of the ecosystem services currently provided by the Southern Ocean for the benefit of mankind. In this framework and within the International Polar Year 2007-2009, 19 research voyages were coordinated by CAML, involving more than 400 biologists from over 30 nations.

The CAML community explored the unknown bathyal and abyssal Southern Ocean (SO) and many shallow sites. Within the project about 16,000 SO taxa were identified and included in a database of Antarctic Marine Life; see the SCAR-Marine Biodiversity Information Network (www.scarmarbin.be). The CAML projects barcoded more than 3,000 species, a SO Plankton Atlas was established, life underneath the collapsed Larsen A and B ice shelves was studied and many scientists worked on the biodiversity, biogeography and conservation of various marine taxa.

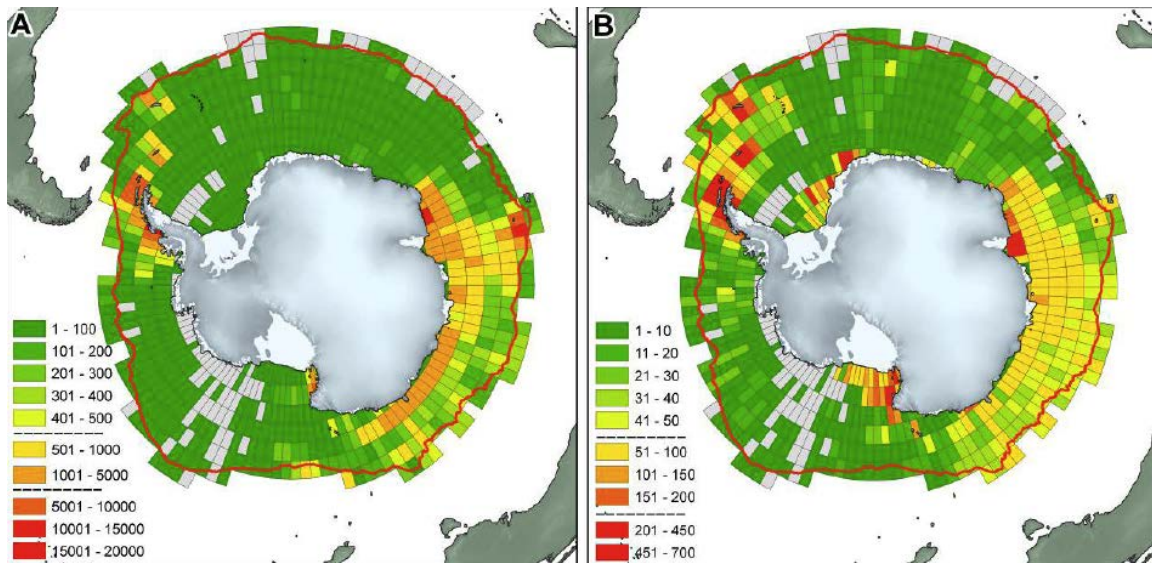
Moreover, more than 700 species new to science were discovered (Brandt et al., 2007) and new and unknown habitats were explored, e.g., the SO deep sea, and the Amundsen Sea. The lasting legacy of CAML is a benchmark, a system (or database) for monitoring change in the SO. Another major legacy of the CAML project and the SCAR Marine Biodiversity Network is the Biogeographic Atlas of the Southern Ocean (De Broyer and Koubbi, 2014) which compiles in more than 80 chapters an extensive review of the state of knowledge of the distributional patterns of the major benthic and pelagic taxa and of the key communities in the SO within an ecological and evolutionary framework. The Atlas relies on vastly improved datasets, and on insights provided by innovative molecular and phylogeographic approaches, and new methods of analysis, visualisation, modelling and prediction of biogeographic distributions. A dynamic online version of the Biogeographic Atlas will be hosted on www.biodiversity.aq.

The development of molecular techniques is a technical advance which promises to revolutionize work on the diversity and biogeography of Antarctic marine biota. CAML supported these efforts through its DNA Barcoding program. This technology is rapidly evolving and becoming ever more sophisticated. In particular such work is starting to uncover a wealth of cryptic species within what were once regarded as single, widely distributed species. Not only does this work increase the known species richness of the SO, but it also changes biogeographic patterns (typically reducing the range size or depth range) and hence affects our interpretation of the evolutionary history of the fauna. Along with these techniques, recent advances in satellite and aerial imagery will also become important for mapping and visualization and will help improve knowledge of marine ecosystems in the Southern Ocean. The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is regarded as a model for regional cooperation and maintains scientific research programmes (including ecosystem monitoring) to address risks to commercially exploited fish stocks in the SO using an ecosystem-based approach.

Despite the recent outstanding progress, some problems, gaps in knowledge and questions remained unaddressed (Griffiths et al., 2011). Besides obvious geographic and sampling gaps which still exist in the SO (East Antarctic, the Amundsen and Bellingshausen Seas and the SO deep sea, Figure 5), the extent of our knowledge of the biology, distribution, zoogeography, and evolution of Antarctic species is size-dependent.

The smaller the species are (nano-, meiobenthos, <1mm), the less is known about them. This also includes a lack of information on species' life histories and their diets, as our knowledge of the SO food web is mainly based on the diets of large pelagic predators. It is largely unknown what bottom dwellers feed on. This might be due to the fact that scientific effort and sampling of the benthos has predominantly concentrated on the continental shelves. Besides this bias in sampling depths, additional knowledge gaps are due to bias in the sampling gear used, with different gear considered as being either quantitative or qualitative (corers vs. trawled gear). Different working groups and expeditions have used different mesh sizes (not all scientists use fine mesh-sized gear and sieves), protocols and fixation methods.

In many marine areas (especially in the deep sea) more than 50 per cent of all species are rare and occur in samples as singletons. The fact that species occurrences are unevenly distributed – depending on their evolution and the availability of food sources – makes it difficult to understand the phenomena of patchiness and/or rarity. Very little is known at the community level about the potential effects of ongoing environmental change in the region. Although some shallow-water species have been physiologically investigated (and physiological adaptations are known for certain single species), community-scale effects of stressors, such as temperature rise, ocean acidification, increased frequency of iceberg scouring, etc., are very little known completely unknown (See Appendix 1-Southern Ocean for a summary of assessments).



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 5. The total number of all marine sample sites and species found within each cell of a 3° of latitude by 3° of longitude grid, from distribution records in SCAR-MarBIN. The red line indicates the mean position of the Antarctic Polar Front, which defines the maximum northern extent of this study. A. Sample sites. B. Species richness (total number of all marine species recorded in that cell). Taken from Griffiths, 2010.

4. Status of Knowledge of Marine Biodiversity: A Synthesis United the Ocean Biogeographic Information System (OBIS)

4.1 Taxonomic completeness

Appeltans et al. (2012) estimated at about 226,000 the number of eukaryotic marine species described. More importantly, these authors report that more species were described in the past decade (about 20,000) than in any previous one and that the number of authors describing new species has been increasing at a faster rate than the number of new species described in the past six decades, demonstrating that progress has been made globally. Despite this, between one-third and two-thirds of marine species may be undescribed, representing a major gap. Costello et al. (2010), based on the regional reviews of the state of knowledge of marine biodiversity compiled worldwide by the Census of Marine Life, provided a global perspective on what is known and what the major scientific gaps are. They concluded that although there have been significant surveys and research efforts over the years, many habitats had been poorly sampled, especially in the deep sea, and several species-rich taxonomic groups, especially of smaller organisms, were still poorly studied. The best-known groups, which together comprise more than 50 per cent of total known biodiversity across regions, are

crustaceans, molluscs, and fishes. However, knowledge of marine biodiversity is not only related to surveys but also to the availability of local and regional taxonomic expertise, and to commercial value (e.g. fish and crustaceans). Here we examine the current global availability of biogeographic knowledge across all major marine taxa, using OBIS (OBIS; IOC of UNESCO, 2014) data.

Overall, the figure includes data for 228,935 accepted marine species across all taxonomic kingdoms (Figure 6). Forty per cent (90,921) of these species, including at least one representative from each major taxonomic group, contribute to the total of 28,369,304 OBIS distribution records. This figure shows that very few groups have more than 50 per cent of their species represented in OBIS (mammals, birds, bony fish, sharks and rays, and other fishes among the vertebrates and echinoderms, cephalopods, corals and anemones among the invertebrates). For example, over 80 per cent (13.7K) of the 16.7K known species of bony fish have a record in OBIS; on average these 13.7K species are known from between 10 and 100 distribution records (median = 25). The maximum number of records in OBIS is 849,179 and corresponds to the Atlantic cod *Gadhus morhua*. The typical species occurring in OBIS has just 6 distribution records, and 20 per cent of them (18,181 species) are represented by only a single record. Nonetheless, 27 of the 30 groups considered here include at least one species with >1,000 distribution records, with 17 and 7 groups, respectively, including species with >10,000 and >100,000 records.

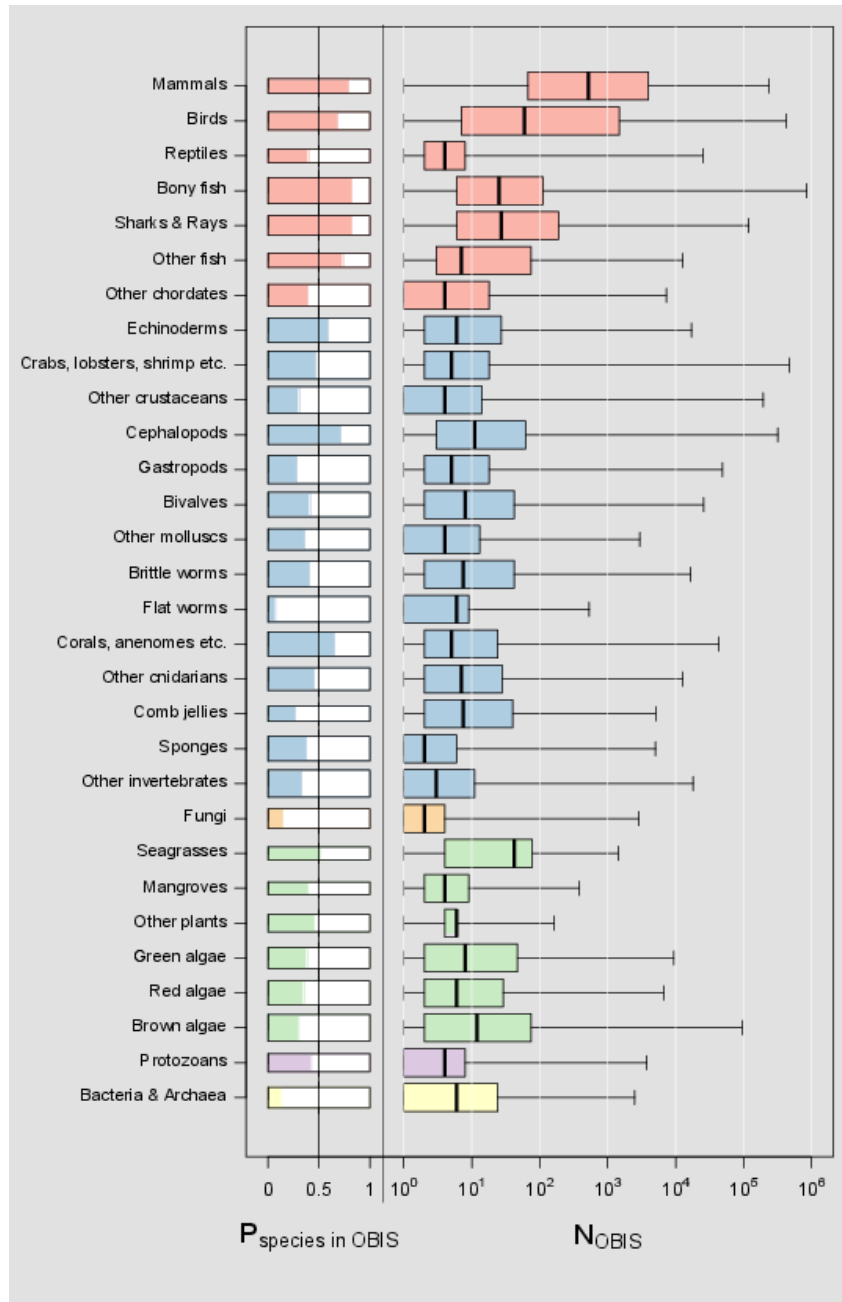
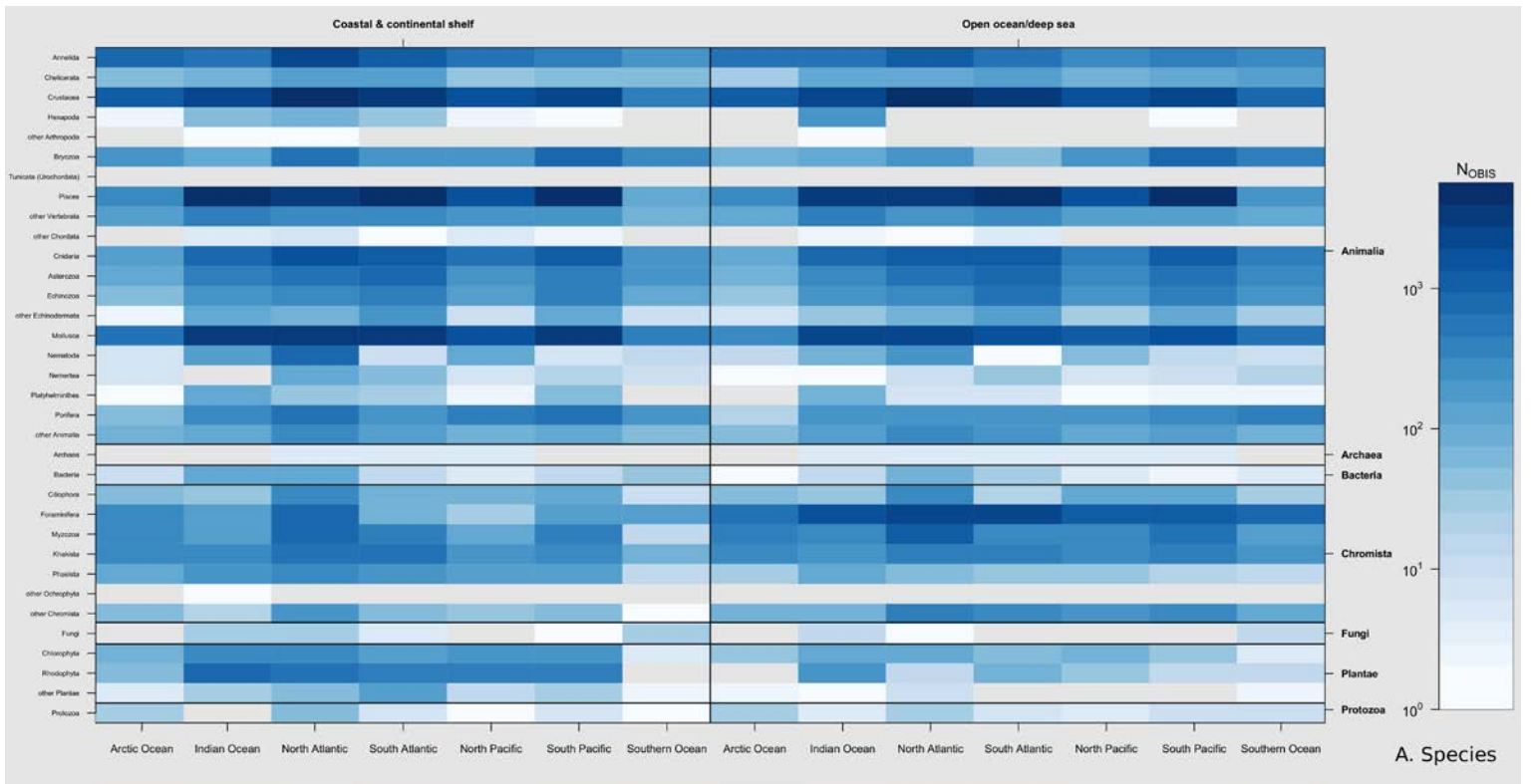


Figure 6. Summary of the current global availability of biogeographic knowledge across all major marine taxa, using Ocean Biogeographic Information System data. The left-hand panel shows, for each taxonomic group, the proportion of all known species within that group which have at least one distribution record in OBIS ($P_{\text{species in OBIS}}$), with the solid vertical line indicating data available for 50 per cent of species. The thickness of each bar is scaled to the number of described species in each group, according to the World Register of Marine Species (WoRMS; WoRMS Editorial Board, 2014). The right-hand panel shows for each group the number of records across all species occurring in OBIS (N_{OBIS}). The solid bar is the median, the coloured box shows the interquartile range, and the lines extend to the minimum and maximum number of records for each group. Colours indicate: red (vertebrates), blue (invertebrates), orange (fungi), green (plant and algae), purple (protozoans), yellow (bacteria and archaea).



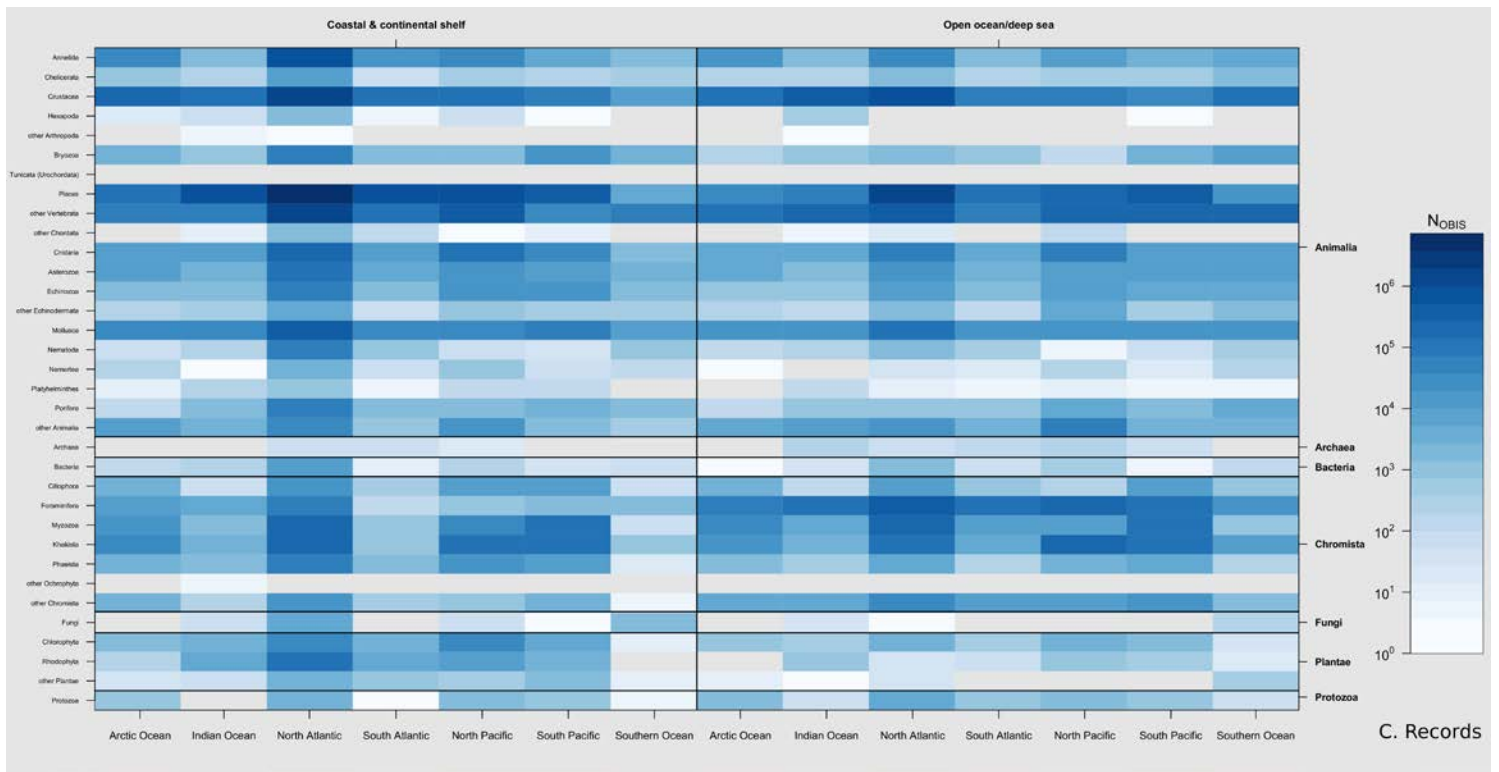


Figure 7 provides a visual representation of our knowledge measured as number of observations for species (7A), sampling (7B), and records (7C) for the different taxonomic groups comparing coastal and continental shelf environments versus open ocean and deep sea waters for the seven ocean basins. In general, it is clear from Figure 7A that fishes, along with crustaceans and molluscs, are the most diverse groups in all ocean basins. Figures 7B and C show that the North Atlantic is the best-known ocean basin for all groups. (www.iobis.org). These figures also demonstrate that, for each of the ocean basins, knowledge is significantly higher in the coastal and continental shelf environments in comparison to the open ocean and deep sea environments which reflects the same situation exposed by Costello et al. (2010), four years later despite important efforts in advancing deep sea research. To analyse geographic completeness, we show an estimate of the number of species using the Chao index for the different seas within the seven ocean basins using the OBIS database. It is evident from this graph that the best sampled areas have been in the northern hemisphere, and that the southern hemisphere, with the exception of the Southern Ocean, has been poorly sampled (Figure 8).

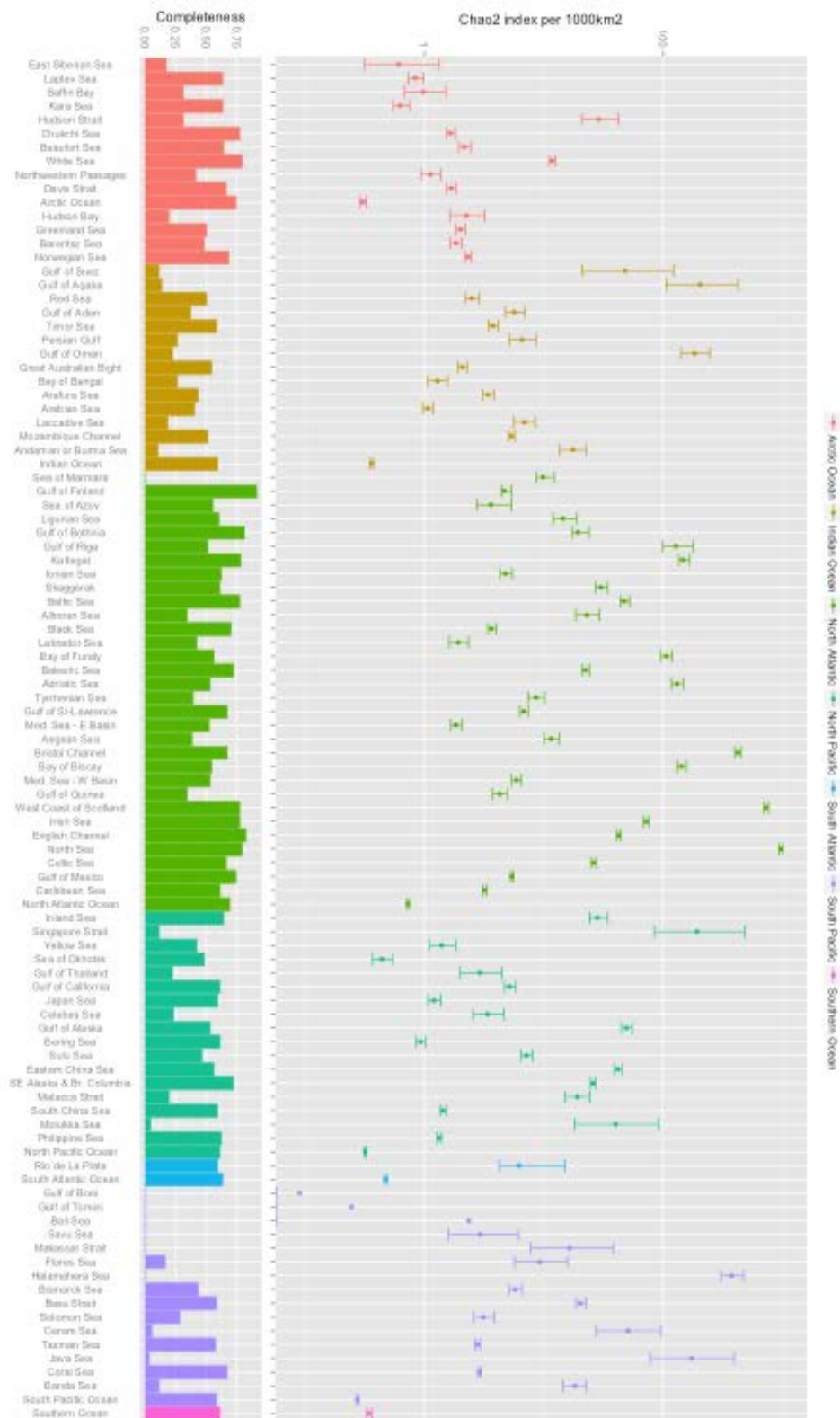


Figure 8. Estimate of the number of species, using the Chao index, for the different seas within the seven ocean basins using the OBIS database (www.iobis.org).

Final remarks

Marine biodiversity assessments are very variable among taxonomic groups and among ecosystems. Best assessed are groups such as fish, sea mammals, sea birds, turtles, and plankton, and ecosystems such as coral reefs. However, assessments are mostly limited in time, as very few have long term series data (as, for example, the CPR -Continuous Plankton Recorder has), and are limited by geographic range and taxonomic representation. Regarding taxonomic representation, for example, among fish efforts are mostly focused on commercial species (stock assessments) and top predators.

Among large vertebrates, efforts are focused on “iconic” and/or under-threat large species such as whales and turtles. Regarding geographic range, there is a considerable amount of information on coastal shelves and slopes along developed nations (e.g. Europe, United States, Canada, Australia, Japan, South Africa), however, even in these regions, knowledge is patchy in time (very few sustained long term efforts) and space (concentrated in particular areas of those coasts). The Arctic and Southern Ocean have received considerable attention (again the “charismatic” reason), but due to habitat complexity and logistical challenges, knowledge is fragmented, with some areas very poorly known. A generalized problem common to developed and developing countries, is that there is much unpublished data (at least not available through open access databases).

In addition, the ecosystem-approach type of assessment leading to an integrated management strategy is very recent, and still not widely used. Coral reefs may be the pioneer ecosystems in which this approach has been used, as monitoring programmes measure live cover, abundance and biomass in addition to biodiversity. This approach is also extending to other shallow water communities such as rocky shores through the integration of data and the creation of international networks. In the deep sea, seamounts seem to be the best assessed ecosystems, again maybe due to their potential economic value for fisheries or other extractive harvests such as minerals, as well as their potential to support significant biodiversity. This creates the urge to understand what they have in terms of living resources so that they can be managed properly before serious exploitation begins. On geologically active ecosystems such as vents and seeps, no assessments have been carried out, and information about these is very recent, very patchy, and very scarce.

We continue to stress the importance of taxonomy, systematics, and studies of biodiversity to advance our knowledge of ecology, ecosystem-based management, and understanding/valuation of ecosystem services. These are especially needed with increasing extinction rates, continued anthropogenic pressures on biodiversity, and the consequences of human-induced climate change. In this sense, biogeographic information is of fundamental importance for discovering marine biodiversity hotspots, detecting and understanding impacts of environmental changes, predicting future distributions, monitoring biodiversity, or supporting conservation and sustainable management strategies. The major challenges and needs for obtaining a more comprehensive overview of global marine biodiversity are the need to: (1) invest in taxonomy and capacity-building; (2) standardize methodologies to ensure proper

comparisons; (3) increase sampling effort, exploring new habitats, and identifying and mapping biodiversity hotspots; (4) make historical and new data increasingly more accessible through open access data portals such as OBIS; (5) quantify ecosystem services and the impact of loss of biodiversity on these goods and services in different marine habitats and ecosystems across regions, and analyze how cumulative and synergistic anthropogenic impacts may affect these services; and (6) continue to enhance the importance of biodiversity in marine management policy decisions.

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