Chapter 6B
Marine invertebrates

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Keynote points

- As of 2019, 153,434 marine benthic invertebrate species had been described globally.
- Since 2012, researchers have described 10,777 new marine benthic invertebrate species; at the same time, biodiversity is changing globally at rates unprecedented in human history, creating the potential for species extinction before they have been described.
- The deep sea covers 43 per cent of the Earth's surface, with an estimated 95 per cent of marine invertebrate species still undescribed.
- Major pressures on marine invertebrates include temperature increase, ocean acidification, physical impacts on the seabed, the extraction of living and non-living resources, coastal use, invasive species and pollution.
- Large areas of the globe, including areas beyond national jurisdiction, still lack effective and adequate long-term ecosystem monitoring and protection for marine invertebrates.
- Despite new research regarding many important ecosystem processes, functions, goods and services, huge knowledge gaps remain in understanding the impact of reductions in benthic invertebrate biodiversity on human well-being and ecosystem dynamics.

1. Introduction

The present subchapter focuses on benthic shrimps, worms, gastropods, bivalves and other invertebrates living on or in the sea floor that are important food sources for fishes, marine mammals, seabirds and humans, as well as invertebrate species that are targeted by some commercial fisheries. Those taxa form the basis for some of the most productive ecosystems on the planet (e.g., estuaries and coral reefs), rivalling tropical forests (Valiela, 1995) and creating habitats covering more of the Earth's surface than all other habitats combined (Snelgrove and others, 1997). Changes in ocean use, the harvesting of organisms, climate change, pollution and invasive species contribute to global alterations in nature at rates unprecedented in human history. Historically, coastal biota have experienced greater pressures and impacts than the deep sea, but the depletion of coastal marine resources and new technologies create both the capacity and incentive to fish, mine and drill in some of the deepest parts of the ocean (McCauley and others, 2015). Alterations of biodiversity often erode economies, livelihoods, food security, health and quality of life worldwide (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019).

2. Summary of the situation recorded in the first *World Ocean Assessment*

In the first *World Ocean Assessment* (United Nations, 2017b), major drivers and patterns of marine invertebrate biodiversity were identified, from regional to global scales. Complex interactions among drivers, as well as their individual and collective impacts on marine biodiversity at multiple scales of biological organization and observation, limit current capacity to predict regional diversity with confidence. Coastal and oceanic patterns differ globally, and coastal benthic species richness generally peaks near the equator and declines polewards, in contrast to mid-latitude peaks in oceanic species. However, strong longitudinal gradients complicate coastal patterns, with localized hotspots of biodiversity across many taxa in areas such as the tropical Indo-Pacific and the Caribbean.

Areas of low oxygen, bottom instability, variation in ocean chemistry, habitat variables and maritime activities complicate the prediction of marine invertebrate diversity patterns in space and time. The multiple drivers of change, often acting in tandem, make it extremely difficult to disentangle natural changes from human-induced pressures. Biodiversity hotspots often attract and support human extractive activities, directly linking ocean biodiversity and ecosystem services. Moreover, those hotspots also often support important ecosystem functions, such as nutrient recycling, food web support and habitat creation that, in turn, contribute to ecosystem services of direct benefit to humans.

3. Description of environmental changes (2010–2020)

3.1. Marine invertebrate biodiversity

Records in the World Register of Marine Species (WoRMS) (Vandepitte and others, 2018; WoRMS Editorial Board, 2019), indicate that 10,777 new valid marine benthic invertebrate species were described between 2012 and 2019, bringing the total number of such species described globally to 153,434. The taxon Mollusca contain the highest numbers of described marine benthic invertebrate (31 per cent), followed by Arthropoda (24 per cent).

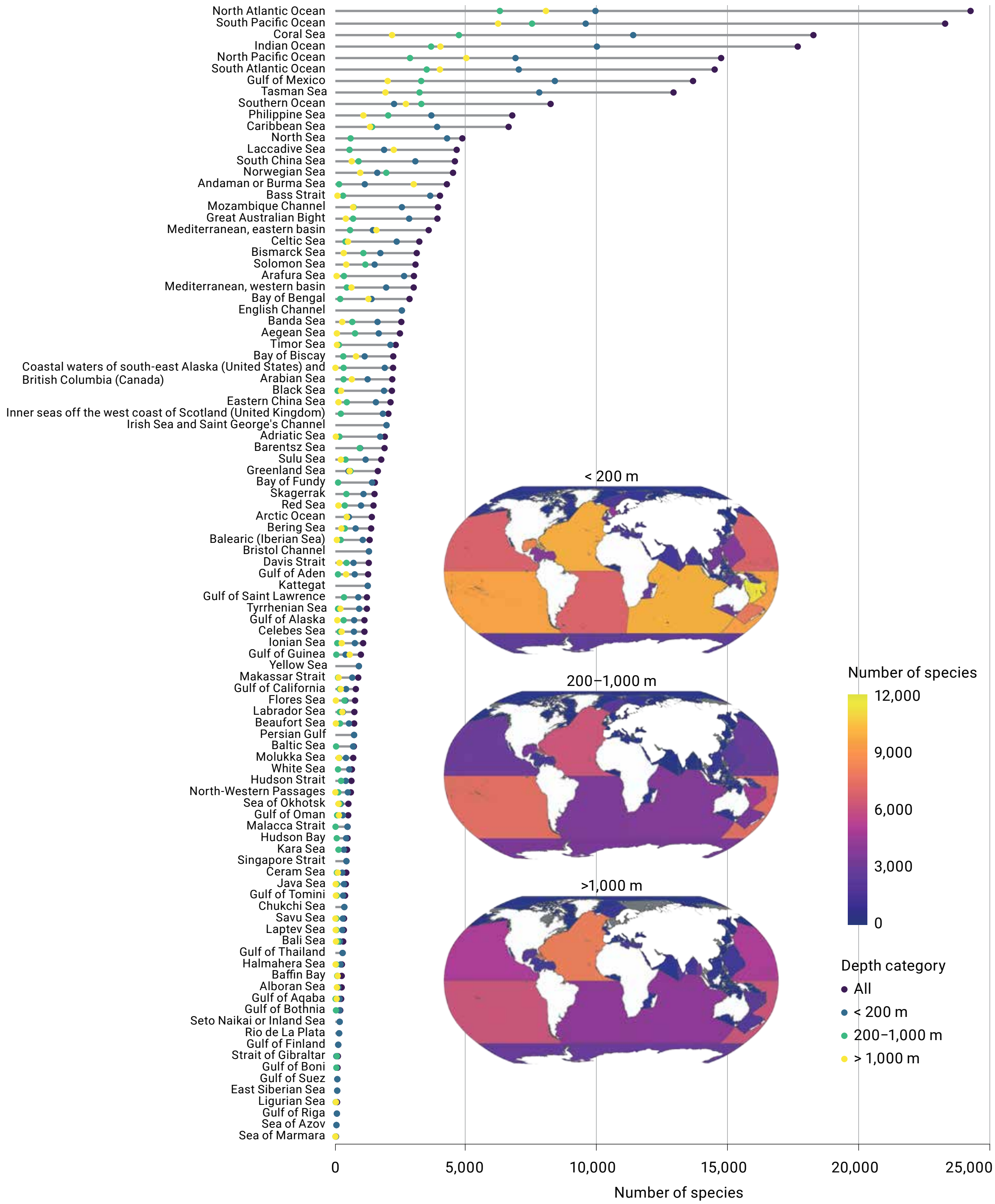
The Ocean Biodiversity Information System (OBIS) contains distribution information for 124,372 marine species, representing 56.4 million distribution records. Among those, WoRMS currently identifies 80,132 species as marine benthic invertebrates, representing 8.1 million distribution records.

According to the data available in OBIS and WoRMS in 2019 (see figure I), the well-sampled North Atlantic Ocean contains the highest numbers of recorded marine benthic invertebrate species (24,214 species), followed by the comparatively undersampled South Pacific Ocean (23,245 species), including the Coral Sea (18,224 species), which will certainly yield many more yet undiscovered species.

A study based on bathymetric zones (see figure I) reveals that the Coral Sea contains the highest number of species recorded at depths shallower than 200 m (11,353 species), followed by the Indian Ocean (9,971), the North Atlantic Ocean (9,915) and the South Pacific Ocean (7,498). In some instances (e.g., Bering Sea, Arctic Ocean and Norwegian Sea) similar latitudes differ in benthic diversity. Below 1,000 m, the better-sampled (relative to other basins) North Atlantic Ocean contains the highest number of species (8,027).[1]

[1] Distribution information is not available for all species described in the World Register of Marine Species (WoRMS). The Ocean Biodiversity Information System (OBIS) constantly receives input from many data providers and shows the exact ocean locations where marine species have been recorded. Because WoRMS documentation of benthic traits is ongoing, some 11,000 of the invertebrate species in OBIS still lack functional group designations, and the overview therefore omits those marine benthic invertebrate species.

Total numbers of recorded marine invertebrate benthic species represented as three depth categories (< 200 m, 200–1,000 m and > 1,000 m)



Source: OBIS (2019) for species occurrences; WoRMS for species group information; EMODnet (2016), GEBCO (2015) and Provoost and Bosch (2018) for bathymetry data; and adapted from Marineregions.org (Claus and others, 2014; Flanders Marine Institute (2018)) for sea areas.

3.2. Assessment and state of marine invertebrate biodiversity

Globally, multiple pressures and drivers affect marine benthic invertebrates simultaneously (see table below). While those impacts have been the subject of many studies around the globe, the present section and the table below highlight only some recent targeted or valuable time series studies that illustrate increased understanding since the first Assessment.

3.2.1. Climate warming

Strong evidence indicates unabated warming of the global ocean since 1970, which has taken up more than 90 per cent of the excess heat in the climate system. Since 1993, the rate of ocean warming has probably more than doubled (Intergovernmental Panel on Climate Change (IPCC), 2019). Impacts on marine benthos are particularly profound for polar and subpolar regions. Sea ice reduction in the Arctic will increase ship access to the region, potentially increasing local anthropogenic pressure on benthic communities, in particular in harbours.

Recent findings

- In the Arctic,[2] the Barents Sea (Jørgensen and others, 2019), other seas to the north of Eurasia and the Far Eastern seas in the North Pacific (Lobanov and others, 2014), marine invertebrates are shifting northwards as a result of warming waters (see table). Invertebrate biomass has declined in areas of the Alaska seas (see table) (Grebmeier and others, 2015) with consequences for higher trophic levels (Grebmeier, 2012); native elders link this change to decreased sea ice coverage, the movement of sand bars and alterations in ocean currents (Metcalf and Behe, in Jørgensen and others, 2017).
- In the North Atlantic, climate warming has enabled the arrival of warm-water species in inshore areas of the United Kingdom of Great Britain and Northern Ireland (see table) influenced by the Gulf Stream (Birchenough and others, 2015).
- In the Pacific, marine heatwaves have led to severe bleaching and mass mortality of corals around Australia (Le Nohaïc and others, 2017; Hughes and others, 2018; Stuart-Smith and others, 2018), the Central American coast (Cruz and others, 2018) and the South China Sea (see table).

Some researchers predict increasing frequency and severity of marine heatwaves (Frölicher and Laufkötter, 2018) in the coming decades, even if emission-reduction targets established under the Paris Agreement[3] are met. This warming could eliminate key biogenic habitats in coastal regions of temperate and Arctic seas worldwide (Krumhansl and others, 2016) and affect reef ecosystems located in poorly monitored waters with unknown damage (Genevier and others, 2019).

3.2.2. Bottom trawl fisheries

Bottom trawl fisheries are the most widespread source of anthropogenic physical disturbance to global seabed habitats, and almost one quarter of global seafood landings were caught by bottom trawls from 2011 to 2013 (Hiddink and others, 2017). Trawl gear removes 6–41 per cent of faunal biomass per pass and median recovery times are 1.9–6.4 years (excluding the deep sea), depending on the fishery and environmental context (ibid.). Trawling impact studies demonstrates that decreases in the relative abundance of long-lived fauna (> 10 years) in trawled areas are greater than those of fauna with shorter life spans (1–3 years) (Hiddink and others, 2019).

[2] See www.arcticbiodiversity.is/index.php/findings/benthos.
[3] See FCCC/CP/2015/10/Add.1, decision 1/CP. 21, annex.

Selected national case studies and related natural and anthropogenic drivers and pressures

	Arctic Ocean			North Atlantic Ocean							South Atlantic Ocean	Indian Ocean		North Pacific Ocean			South Pacific Ocean		Indian Ocean-South Pacific Ocean boundary
	Norway and Russian Federation, Barents Sea	Russian Federation, Arctic seas	United States, Arctic	Canada, north-east	Greenland, west and south-east	United Kingdom, North Sea	Portugal, south-west	Greece, bays and gulfs	Malta, coast	Trinidad and Tobago	Brazil, coast and bays	Bangladesh, coast	Australia, west	Viet Nam, coast	South China Sea	Russian Federation, eastern seas	Australia, north-east	New Zealand, east	Australia, south
Climate warming	x	x	x	x	x	x									x	x			x
Temperature events (e.g., El Niño)													x	x			x		
Sedimentation								x		x	x	x		x					
Storms and wave action										x		x	x				x		
Bottom trawl fisheries	x			x	x	x	x	x				x		x	x	x		x	x
Overharvesting of invertebrates											x								
Spreading of new species	x	x	x	x			x		x		x								
Outbreaks of species										x							x		x
Pollution								x			x	x		x	x				
Eutrophication (from agriculture, aquaculture and sewage)								x			x				x				
Oil and gas exploitation and extraction				x		x				x	x				x				x
Offshore wind farms						x													
Large ship-breaking activities												x							
Anchoring								x	x		x								
Coastal infrastructure development								x	x		x				x				
Tourism								x	x		x	x							

Recent findings

- Bottom trawling alters native benthic communities, with impacts characterized as “some modifications” in the North Sea. Studies conducted elsewhere in the North Atlantic and beyond report similar changes in benthic communities resulting from aggregate dredging (Cooper and others, 2017) and experimental trawling (Kenchington and others, 2006), the imposition of “one of the largest footprints per unit of biomass landed” in south-west Portugal (Ramalho and others, 2018) and negative impact on macro-epibenthic composition in southern Greenland (Yesson and others, 2016).
- On bathyal seamounts in the South Pacific, east of New Zealand, the recovery of coral communities after the use of heavy ground gear will likely take many decades (Clark and others, 2019).
- In the North Pacific, negative impacts of bottom trawling on macro-epibenthic composition were reported in the East China Sea (Wang and others, 2018).
- Discarded or lost fishing gear has significant impacts on cold-water coral assemblages (Deidun and others, 2015) at depths of hundreds of metres.
- Invertebrate fishery catches (see also chap. 15) have rapidly expanded globally to more than 10 million tons annually and contribute significantly to global seafood provision, export, trade and local livelihoods. On average, 90 per cent of invertebrate catch can be achieved at a 25 per cent depletion rate, requiring less fishing effort, thereby raising profits, while strongly reducing impacts on other trophic groups (Eddy and others, 2017).
- The harvesting of scallops (*Chlamys islandica*) in the Arctic (Barents Sea) (Nosova and others, 2018) and of sea cucumbers, scallops and crabs in the eastern seas of the Russian Federation (Lysenko and others, 2015) is altering biogenic habitats.

3.2.3. Invasive species

Invasive species (see also chap. 22 and the International Association for Open Knowledge on Invasive Alien Species)[4] occasionally become a dominant pressure on native benthos.

Recent findings

- According to studies on the expanding range of the commercial, predatory snow crab (*Chionoecetes opilio*) in the Arctic, *C. opilio* removes nearly 30,000 tons of macrobenthos in the eastern Barents Sea annually (see table) (Zakharov and others, 2018).
- In the North Atlantic, the invasive green crab (*Carcinus maenas*) has had an impact on seagrasses and sea floor invertebrates in some Canadian coastal areas[5] (see table) (Garbary and others, 2014, Matheson and others, 2016). Extensively invasive *Sargassum* algae (see also chaps. 6E and 6G) now cover beaches and inshore coastal habitats of Trinidad and Tobago and other Caribbean islands (Gobin, 2016). Extensive *Sargassum* beds can alter the abundance of many native marine invertebrates and may provide a suitable habitat for species not previously represented in the local benthic community.
- In the Mediterranean, more than 500 non-indigenous marine invertebrate species have been recorded (Tsiamis and others, 2019), many of which have become established, at least locally, at many sites.
- Outbreaks of the sea urchin *Centrostephanus rodgersii* are degrading kelp forests off the coast of Tasmania, Australia (Ling and Keane, 2018).
- In the South Atlantic, invasive species frequently dominate some Brazilian coastal reefs (Creed and others, 2016, Mantelatto and others, 2018) (see table).

4 www.invasivesnet.org/news.
5 Available at: www.dfo-mpo.gc.ca/species-especes/ais-eae/about-sur/index-eng.html.

3.2.4. Consequences of pollution on seabed communities

The consequences of pollution on seabed communities were well documented in the first *World Ocean Assessment* and by IPBES (IPBES, 2019). To assess the environmental state and the resilience of benthic invertebrates, their behaviour, dynamics and multiple interactions with the environment need to be studied (Neves and others, 2013, Pessoa and others, 2019).

Recent findings

- Agricultural run-off and the disposal of municipal waste into the ocean add nutrients that produce algal blooms, which eventually sink to the bottom, creating hypoxic conditions and low pH that typically reduce benthic species diversity. Since the first Assessment, additional algal blooms have been reported by researchers in the Indian Ocean, along the coast of Bangladesh (Kibria and others, 2016; Mallick and others, 2016; Molla and others, 2015), and in the South Atlantic, along the coast of Brazil (Cruz and others, 2018) (see table).
- In the North Atlantic, outflow (sedimentation) from the Orinoco River (Trinidad and Tobago) (see table) increases potential contamination and mortality of benthic invertebrate communities (Gobin, 2016), while a metalliferous discharge caused a multi-year decline in the ecological status of benthic communities along the coast of Greece (Simboura and others, 2014) (see table).

3.2.5. Storms and wave action

Cyclones and tsunamis are among the most critical variables in shaping the biological richness and structure of marine benthic communities and significantly challenging their resilience and stability (Betti and others, 2020). Hurricane frequency and intensity have increased in recent decades along the tropical Atlantic, in close association with climate change-related influences (see references in Hernández-Delgado and others, 2020).

3.2.6. Mining of deep-sea minerals

The mining of deep-sea minerals (see also chap. 18) is a potential new industry that can help to support an expanding "green" economy based on new battery technology for electric vehicles, wind turbines and improved telecommunications and computing technology (Hein and others, 2013). Although no deep-sea mining is currently conducted in the high seas, the International Seabed Authority administers 30 exploration licences (covering an area of 1.5 million km^2) in the Pacific Ocean and the Indian Ocean and along the Mid-Atlantic Ridge. In mining operations, the direct physical removal of sea floor fauna and secondary effects from sediment plumes or the release of ecotoxins will potentially affect benthic environments and will require careful evaluation (Miller and others, 2018). Lack of knowledge of deep-sea biodiversity is a major constraint to ensuring environmental sustainability (Glover and others, 2018).

3.2.7. Human recreational activities, coastal infrastructure development and ship anchoring and bunkering

Human recreational activities, coastal infrastructure development and ship anchoring and bunkering continue to have an impact on vulnerable habitats and associated invertebrate assemblages, as discussed in the first Assessment, with additional records from near Malta (see table) in the Mediterranean (García-March and others, 2007; Mifsud and others, 2006). In addition, ship-breaking activities on the coast of Bangladesh (see table), in the Bay of Bengal, have reduced benthic species diversity (Hossain, 2010).

3.2.8. Crime

The criminal exploitation of marine species occurs globally, as illustrated by the smuggling of abalones out of South Africa by crime groups. A request for assistance from law enforcement agencies in receiving countries may provide a solution (Warchol and Harrington, 2016).

3.2.9. Consequences of changes in marine invertebrate biodiversity on human communities, economies and well-being

Biodiversity changes have both direct and indirect impacts on human well-being (IPBES, 2019). Unfortunately, there is a lack of large-scale and long-term monitoring of large marine areas, even though some Arctic and North Atlantic nations have established long-term monitoring of invertebrate fisheries and by-catch from trawls within existing scientific national fish-assessment surveys (Jørgensen and others, 2017).

Limited publications document specifically how marine benthic invertebrates contribute to human well-being (e.g., Officer and others, 1982; Snelgrove and others, 1997). However, the first and the present Assessments document the importance of benthic invertebrates to marine food webs and the many habitat-forming or habitat-engineering benthic species. Some key issues are summarized below.

- Under a business-as-usual emissions scenario, the United Nations Educational, Scientific and Cultural Organization predicts that the Great Barrier Reef of Australia, along with other World Heritage coral reefs, will have ceased to exist as a functioning coral reef ecosystem by 2100 (Heron and others, 2017).
- Corals, oysters and other living reefs (see also chap. 7F) can dissipate up to 97 per cent of the wave energy reaching them, thus protecting structures and human lives (Ferrario and others, 2014). This is potentially an important mitigation factor as sea level rises. Artificial coastal barriers to protect coastal infrastructure and human communities from climate-related sea level rise will cost an estimated hundreds of billions of dollars by the latter decades of the twenty-first century (IPCC, 2019).
- Increased risk to food security linked to decreases in seafood availability varies greatly on the local and cultural scales. However, for many coastal indigenous peoples and local communities, the harvesting of benthic invertebrates, in particular intertidal species, contributes significantly to their culture and to community-scale food security (IPBES, 2018a, b; IPCC, 2019).
- Elevated sea surface temperatures have contributed to species range extensions globally, including into South Pacific Tasmanian waters (Pecl and others, 2014), which will likely affect fisheries and possibly tourism in the region, as well as ecosystem services.
- Climate-induced changes in the distribution of many benthic invertebrates may cause an increase in food resource species, a decrease, including their local extinction, or even new such species becoming available to dependent coastal communities (IPCC, 2019). Several studies report changes in the poleward range of sessile invertebrates at a slower rate than that of fishes, but also consider benthic invertebrates more likely to respond directly to changes in temperature and pH (IPCC, 2019). Invasive species, such as the snow crab, support increased commercial harvesting in the Arctic Barents Sea (Jørgensen and others, 2019), whereas the crab *Portunus segnis*, a Lessepsian migrant spreading in the Mediterranean, feeds on fish, shelled molluscs, crustaceans and organic matter, thus having a significant impact on trophic processes in native ecosystems, in addition to being the host of a variety of parasites (Rabaoui and others, 2015). In the Africa and Asia-Pacific regions, the impacts of invasive benthic invertebrates increase the risk of failing to meet food security needs (IPBES 2018b, c).
- In the Mediterranean, infrastructure development (e.g., habitat modification for vessels), which has a direct impact on protected species (e.g., *Cladocora caespitosa*) and commercially important species,

decreases the value of marine ecosystem services.

Despite some progress, there remains a need for addressing the huge knowledge gap concerning the effects of biodiversity loss on human communities, economies and well-being. Understanding the underlying causes of change requires repeated time series studies.

4. International and governmental responses

Several ongoing initiatives reflect a growing priority being given to protecting marine biodiversity, in areas both within and beyond national jurisdiction. These initiatives include science processes, such as the World Ocean Assessment, and legal processes, such as the intergovernmental conference on an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, as well as initiatives of Intergovernmental Organizations, such as the International Seabed Authority.

General Assembly resolution 61/105 of 8 December 2006, on sustainable fisheries, in which the Assembly called for fisheries using bottom-contacting gear to avoid significant adverse impacts on vulnerable marine ecosystems, has been particularly influential on marine fisheries. The expert guidance from the Food and Agriculture Organization of the United Nations (FAO) (FAO, 2009) supported States and regional fisheries management organizations in identifying vulnerable marine ecosystems and operating fisheries in ways compliant with the resolution.

Actions taken in line with resolution 61/105 enhanced existing efforts of regional fisheries management organizations to manage the impacts of fisheries on biodiversity. Targeted spatial and temporal closures and move-on rules, triggered by indicators of the presence of vulnerable marine ecosystems, are now applied in combination with a variety of target and limit catch levels spatial management approaches and gear and effort regulations. The aim of these efforts is to keep the impacts of fisheries on target species, by-catch species, seabed habitats and ecological communities within safe ecological levels (Garcia and others, 2014). The performance of regional fisheries management organizations in delivering the mandate to protect seabed habitats and species has been variable over time and among organizations (Gianni and others, 2016), but the frameworks are considered sound and progress is being made (Bell and others, 2019).

4.1. Recent governmental actions

- Some Arctic and North Atlantic nations have established time and cost-efficient, long-term monitoring of invertebrate by-catch from trawls within existing scientific national fish or shrimp assessment surveys (Jørgensen and others, 2017).
- In the South Pacific, New Zealand government policies[6] prohibit bottom trawling and dredging in order to conserve the deep-sea environment in seamount closure areas and benthic protection areas, and there is evidence that benthic species of concern have benefited from those prohibitions (Kelly and others, 2000).
- In the Arctic, in 2019, the Government of Norway closed 442,022 km^2 to bottom trawling in the Barents Sea (Jørgensen and others, 2020).

[6] See www.mpi.govt.nz/dmsdocument/7242-compliance-fact-sheet-7-benthic-protection-areas-and-seamount-closures.

- In the North Pacific Ocean and the Bohai Sea, strict ecological restoration and fishery resources conservation were introduced in 2018.[7]
- In the inlet of the Indian Ocean, despite rules and regulations to protect the marine ecosystem from hazards and destructive activities, actual implementation remains minimal.
- In the Mediterranean, the conservation status of sponges has recently been locally assessed in the Aegean ecoregion (Gerovasileiou and others, 2018).
- Competent authorities in the member States of the European Union are implementing the Marine Strategy Framework Directive.[8] In the areas concerned, among other descriptors, the sea floor integrity shall be kept at a level that safeguards the structure and function of the ecosystems and does not adversely affect benthic ecosystems. The second cycle of the implementation plans under the Directive[9] increases the protection from fishery impacts of seabed features important to benthic invertebrates. This includes, among others, the banning of mobile bottom-contacting gears at depths shallower than 50 m, to protect vulnerable habitats, such as seagrass beds.

The Convention on Biological Diversity Aichi Biodiversity Target 11,[10] another major global policy initiative, has direct relevance for benthic invertebrates. This initiative calls for a robust conservation strategy based on an effectively and equitably managed, ecologically representative and well-connected system of protected areas (see also Kenchington and others, 2019) and other effective area-based conservation measures, integrated into wider seascapes (see also chaps. 26 and 27). Target 11 includes identifying and spatially delineating areas of protection, ensuring scales matching the spatial and temporal needs of the biodiversity features.

This approach is intended to achieve positive and sustained long-term outcomes for the conservation of biodiversity, in particular seabed invertebrate diversity and associated ecosystem functions and services and, where applicable, cultural, spiritual, socioeconomic and other locally relevant values.

Benthic invertebrate biodiversity could particularly benefit from those developments, given that, as documented in the present subchapter, seabed habitats experience pressures and impacts from many sectors and their associated activities and are so diverse that the effectiveness of specific types of conservation measures vary greatly with specific environmental conditions, history and mixes of human pressures, including climate change.

In general, increasing marine protected area network coverage should reduce pressures on benthic invertebrates and facilitate the recovery of negatively affected areas. Aichi Biodiversity Target 11 contributes to a growing awareness that conservation strategies need to move beyond protecting individual, isolated marine areas (Secretariat of the Convention on Biological Diversity, 2011). Marine protected area networks are essential biodiversity conservation tools designed to improve marine biodiversity protection by encompassing spatial scales that better reflect the life history distributions of species. Target 11 also promotes conservation beyond boundaries by recognizing the crucial role of governance and economic, social and ecological factors working in concert to influence ecological outcomes (Meehan and others, 2020).

7 See www.mee.gov.cn/xxgk2018/xxgk/xxgk03/201812/t20181211_684232.html.
8 Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056.
9 See https://mcc.jrc.ec.europa.eu/main/dev.py?N=24&O=202&titre_chap=D6%20Sea-floor%20integrity&titre_page=Implementation#2016331103713.
10 See www.cbd.int/sp/targets/rationale/target-11.

5. Achievement of relevant Sustainable Development Goals[11] and contribution to Aichi Biodiversity Target 11

Current negative trends in biodiversity and ecosystems will undermine progress towards the achievement of Aichi Biodiversity Target 11, which is aimed at the conservation and integration into the wider landscape and seascape of 10 per cent of coastal and marine areas of particular importance for biodiversity and ecosystem services by 2020, through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures.

6. Key remaining knowledge gaps and capacity-building gaps

6.1. Knowledge gaps

- Studies on the effect of protected areas remain limited.
- Reviews do not break down impacts (e.g., climate change, resource exploitation and pollution) on marine biodiversity by species group. This limits knowledge of the value and importance of invertebrates for human well-being.
- Baseline biodiversity studies (for ecoregions or for habitats that are hotspots for biodiversity) are lacking for the mesophotic zone, underwater caves and many of the thousands of global seamounts.

6.2. Capacity-building gaps in the field

- The large-scale protection of the seabed, at both the national and international levels, must continue in order to sustain benthic biodiversity and avoid the extirpation of species before they have even been recorded.
- Listing species with restricted geographical ranges, often arising from specialized habitat requirements, represents the most urgent need. Even describing 100 taxonomic units every year over the next decade would add just 1,000 species before, according to some experts, commercial scale deep-sea mining is expected to begin (Glover and others, 2018).
- To increase knowledge on biodiversity and ecosystem understanding, marine national regular assessment cruises should report both targeted and non-targeted scientific catch.
- Integrated ocean management should be prioritized to coordinate conservation and management among all relevant activities.
- Managers should develop and implement common, well-defined measures to identify and respond to declining benthic habitats in national and international waters.
- Studies are needed to determine the effects on ecosystems of reduced or lost benthos, in particular in the context of food web interactions.
- Studies are needed to determine the effect on food supply if harvested benthic communities disappear.
- The cumulative impact of drivers and pressures that can have a combined effect on marine biodiversity needs to be assessed.

[11] See General Assembly resolution 70/1.

References

Betti, F., and others (2020). Effects of the 2018 exceptional storm on the *Paramuricea clavata* (Anthozoa, Octocorallia) population of the Portofino Promontory (Mediterranean Sea). *Regional Studies in Marine Science*, vol. 34, 101037.

Birchenough, Silvana N.R., and others (2015). Climate change and marine benthos: a review of existing research and future directions in the North Atlantic. In *Wiley Interdisciplinary Reviews: Climate Change*, eds. Henning Reiss and others, vol. 6, No. 2, pp. 203–223.

Clark, Malcolm R., and others (2019). Little evidence of benthic community resilience to bottom trawling on seamounts after 15 years. *Frontiers in Marine Science*, vol. 6, art. 63.

Claus, Simon, and others (2014). Marine regions: towards a global standard for georeferenced marine names and boundaries. *Marine Geodesy*, vol. 37, No. 2, pp. 99–125.

Cooper, K.M., and J. Barry (2017). A big data approach to macrofaunal baseline assessment, monitoring and sustainable exploitation of the seabed. *Scientific Reports*, vol. 7, art. 12431.

Creed, Joel C., and others (2016). The invasion of the azooxanthellate coral Tubastraea (Scleractinia: Dendrophylliidae) throughout the world: history, pathways and vectors. *Biological Invasions*, vol. 19, No. 1, pp. 283–305.

Cruz, Igor C.S., and others (2018). Marginal coral reefs show high susceptibility to phase shift. *Marine Pollution Bulletin*, vol. 135, pp. 551–561.

Deidun, Alan, and others (2015). First characterisation of a *Leiopathes glaberrima* (Cnidaria: Anthozoa: Antipatharia) forest in Maltese exploited fishing grounds. *Italian Journal of Zoology*, vol. 82, No. 2, pp. 271–280.

Eddy, Tyler D., and others (2017). Ecosystem effects of invertebrate fisheries. *Fish and Fisheries*, vol. 18, No. 1, pp. 40–53.

EMODnet Bathymetry Consortium (2016). *EMODnet Digital Bathymetry (DTM 2016). EMODnet Bathymetry Consortium*. https://sextant.ifremer.fr/record/c7b53704-999d-4721-b1a3-04ec60c87238.

Food and Agriculture Organization of the United Nations (FAO) (2009). International guidelines for the management of deep-sea fisheries in the high seas. Rome. www.fao.org/in-action/vulnerable-marine-ecosystems/background/deep-sea-guidelines/en/

Ferrario, Filippo, and others (2014). The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. *Nature Communications*, vol. 5, art. 3794.

Flanders Marine Institute (2018). IHO Sea Areas, version 3 (accessed on 25 October 2019). https://doi.org/10.14284/323.

Frölicher, T.L., and Laufkötter, C. (2018). Emerging risks from marine heat waves. *Nature Communications*, vol. 9, art. 650.

Garbary, David J., and others (2014). Drastic decline of an extensive eelgrass bed in Nova Scotia due to the activity of the invasive green crab (*Carcinus maenas*). *Marine Biology*, vol. 161, No. 1, pp. 3–15.

García-March, J.R., and others (2007). Preliminary data on the *Pinna nobilis* population in the marine protected area of Rdum Il-Majjiesa to Ras Ir-Raheb (N.W. Malta). Poster presented at the European Symposium on MPAs as a Tool for Fisheries Management and Ecosystem Conservation. Murcia, Spain.

GEBCO (2015). The GEBCO_2014 Grid, version 20150318 (accessed on 25 October 2019). www.gebco.net.

Genevier, L.G., and others, 2019. Marine heatwaves reveal coral reef zones susceptible to bleaching in the Red Sea. *Global Change Biology*, vol. 25, No. 7, pp. 2338–2351.

Gerovasileiou, V., and others (2018). Assessing the regional conservation status of sponges (Porifera): the case of the Aegean ecoregion. *Mediterranean Marine Science*, vol. 19, No. 3, pp. 526-537. https://doi.org/10.12681/mms.14461.

Glover, Adrian G., and others (2018). Point of View: Managing a sustainable deep-sea ‘blue economy’ requires knowledge of what actually lives there. *ELife*, vol. 7, e41319.

Gobin, J. (2016). Environmental Impacts on Marine Benthic Communities in an Industrialized Caribbean Island–Trinidad and Tobago. *Marine Benthos: Biology, Ecosystem Functions and Environmental Impact*. New York: Nova Science Publishers.

Grebmeier, Jacqueline M. (2012). Shifting patterns of life in the Pacific Arctic and sub-Arctic seas. *Annual Review of Marine Science*, vol. 4, pp. 63–78.

Grebmeier Jacqueline, and others (2015). Ecosystem characteristics and processes facilitating persistent macrobenthic biomass hotspots and associated benthivory in the Pacific Arctic. *Progress in Oceanography*, vol. 136, pp. 92–114.

Hernández-Delgado, E.A., and others (2020). Hurricane Impacts and the Resilience of the Invasive Sea Vine, *Halophila stipulacea*: a Case Study from Puerto Rico. *Estuaries and Coasts*, pp. 1–21.

Heron, Scott Fraser, and others (2017). *Impacts of Climate Change on World Heritage Coral Reefs: A First Global Scientific Assessment*. Paris: UNESCO.

Hiddink, Jan Geert, and others (2017). Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. *Proceedings of the National Academy of Sciences*, vol. 114, No. 31, pp. 8301–8306.

Hiddink, J.G., and others (2019). Assessing bottom trawling impacts based on the longevity of benthic invertebrates. *Journal of Applied Ecology*, vol. 56, No. 5, pp. 1075-1084.

Hossain, Maruf Md. M. (2010). *Ship Breaking Activities: Threat to Coastal Environment, Biodiversity and Fishermen Community in Chittagong, Bangladesh*. Publication Cell, Young Power in Social Action.

Hughes, T.P., and others (2018). Large-scale bleaching of corals on the Great Barrier Reef. *Ecology*, vol. 99, No. 2, pp. 501–501.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2018a). *Summary for Policymakers of the Regional Assessment Report on Biodiversity and Ecosystem Services for Africa of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. eds. E . Archer and others. Bonn, Germany: IPBES secretariat.

________ (2018b). *Summary for Policymakers of the Regional Assessment Report on Biodiversity and Ecosystem Services for Asia and the Pacific of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. eds. M. Karki and others. Bonn, Germany: IPBES secretariat.

________ (2018c). *Summary for Policymakers of the Regional Assessment Report on Biodiversity and Ecosystem Services for the Americas of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. eds. J. Rice and others. Bonn, Germany: IPBES secretariat.

________ (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. eds. Sandra Díaz and others. Paris: IPBES secretariat.

Intergovernmental Panel on Climate Change (IPCC) (2019). Summary for Policymakers. In *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. https://report.ipcc.ch/srocc/pdf/SROCC_SPM_Approved.pdf.

Jørgensen, Lis L., and others (2017). Benthos. In *State of the Arctic Marine Biodiversity Report*, pp. 85–107. Conservation of Arctic Flora and Fauna (CAFF).

Jørgensen, Lis L., and others (2019). Impact of multiple stressors on sea bed fauna in a warming Arctic. *Marine Ecology Progress Series*, vol. 608, pp. 1–12.

Jørgensen, Lis L., and others (2020). Responding to global warming: new fisheries management measures in the Arctic. *Progress in Oceanography*, vol. 188, art. 102423.

Kelly, S., and others (2000). Spiny lobster, *Jasus edwardsii*, recovery in New Zealand marine reserves. *Biological conservation*, vol. 92, No. 3, pp. 359-369.

Kenchington, Ellen, and others (2006). Effects of experimental otter trawling on benthic assemblages on Western Bank, northwest Atlantic Ocean. *Journal of Sea Research* vol. 56, pp. 249-270.

Kenchington, Ellen, and others (2019). Connectivity modelling of areas closed to protect vulnerable marine ecosystems in the northwest Atlantic. *Deep Sea Research Part I: Oceanographic Research Papers*, vol. 143, pp. 85–103.

Kibria, Golam, and others (2016). Trace/heavy metal pollution monitoring in estuary and coastal area of Bay of Bengal, Bangladesh and implicated impacts. *Marine Pollution Bulletin*, vol. 105, No. 1, pp. 393–402.

Krumhansl, Kira A., and others (2016). Global patterns of kelp forest change over the past half-century. *Proceedings of the National Academy of Sciences*, vol. 113, No. 48, pp. 13785–13790.

Le Nohaïc, Morane, and others (2017). Marine heatwave causes unprecedented regional mass bleaching of thermally resistant corals in northwestern Australia. *Scientific Reports*, vol. 7, art. 14999.

Ling, Scott D., and John P. Keane (2018). Resurvey of the Longspined Sea Urchin (*Centrostephanus rodgersii*) and associated barren reef in Tasmania. Hobart, Australia: University of Tasmania.

Lobanov, V. B., and others (2014). Chapter 5. Impact of climate change on marine natural systems, 5.6: Far-Eastern seas of Russia. In *Second Roshydromet Assessment Report on Climate Change and its Consequences in the Russian Federation*. Moscow: ROSHYDROMET. pp. 684–743.

Lysenko, V.N., and others (2015). The abundance and distribution of the Japanese sea cucumber, *Apostichopus japonicus* (Selenka, 1867) (Echinodermata: Stichopodidae), in nearshore waters of the southern part of the Far Eastern State Marine Reserve. *Russian Journal of Marine Biology*, vol. 41, No. 2, pp. 140–144.

Mallick, Debbrota, and others (2016). Seasonal variability in water chemistry and sediment characteristics of intertidal zone at Karnafully estuary, Bangladesh. *Pollution*, vol. 2, No. 4, pp. 411–423.

Mantelatto, Marcelo Checoli, and others (2018). Invasion of aquarium origin soft corals on a tropical rocky reef in the southwest Atlantic, Brazil. *Marine Pollution Bulletin*, vol. 130, pp. 84–94.

Matheson, K., and others (2016). Linking eelgrass decline and impacts on associated fish communities to European green crab (Linnaeus 1758) invasion. *Marine Ecology Progress Ser*ies, vol. 538, pp. 31–45.

McCauley, Douglas J., and others (2015). Marine defaunation: Animal loss in the global ocean. *Science*, vol. 347, No. 6219, 1255641.

Meehan, Mairi C., and others (2020). How far have we come? A review of MPA network performance indicators in reaching qualitative elements of Aichi Target 11. Conservation Letters, e12746.

Mifsud, C., and others (2006). The distribution and state of health of *Posidonia oceanica* (L.) Delile meadows along the Maltese territorial waters. *Biologia Marina Mediterranea*, vol. 13, No. 4, pp. 255–261.

Miller, Kathryn A., and others (2018). An overview of seabed mining including the current state of development, environmental impacts, and knowledge gaps. *Frontiers in Marine Science*, vol. 4, art. 418.

Molla, H.R., and others (2015). Spatio-temporal variations of microbenthic annelid community of the Karnafuli River Estuary, Chittagong, Bangladesh. *International Journal of Marine Science*, vol. 5, No. 26, pp. 1–11.

Neves, R.A.F., and others (2013). Factors influencing spatial patterns of molluscs in a eutrophic tropical bay. *Marine Biological Association of the United Kingdom. Journal of the Marine Biological Association of the United Kingdom*, vol. 93, No. 3, pp. 577–589.

Nosova, Tatyana, and others (2018). Structure and long-term dynamics of zoobenthos communities in the areas of scallop *Chlamys islandica* beds at Kola Peninsula. *Izvestiya TINRO*, vol. 194, pp. 27–41. https://doi.org/10.26428/1606-9919-2018-194-27-41.

OBIS (2019). Ocean Biogeographic Information System. 2019. www.obis.org.

Pecl, Gretta, and others (2014). Redmap: ecological monitoring and community engagement through citizen science. *Tasmanian Naturalist*, vol. 136, pp. 158–164.

Pessoa, L.A., and others (2019). Intra-annual variation in rainfall and its influence of the adult's *Cyprideis* spp. (Ostracoda, Crustacea) on a eutrophic estuary (Guanabara Bay, Rio de Janeiro, Brazil). *Brazilian Journal of Biology*, (AHEAD).

Provoost, Pieter, and Samuel Bosch (2018). obistools: Tools for data enhancement and quality control. Ocean Biogeographic Information System. Intergovernmental Oceanographic Commission of UNESCO. https://cran.r-project.org/package=obistools.

Rabaoui, Lotfi, and others (2015). Occurrence of the lessepsian species *Portunus segnis* (Crustacea: Decapoda) in the Gulf of Gabes (Tunisia): first record and new information on its biology and ecology. *Cahiers de Biologie Marine*, vol. 56, No. 2, pp. 169–175.

Ramalho, Sofia P., and others (2018). Bottom-trawling fisheries influence on standing stocks, composition, diversity and trophic redundancy of macrofaunal assemblages from the West Iberian Margin. *Deep Sea Research Part I: Oceanographic Research Papers*, vol. 138, pp. 131–145.

Secretariat of the Convention on Biological Diversity (2011). Strategic plan for biodiversity 2011–2020: Provisional technical rationale, possible indicators and suggested milestones for the Aichi Biodiversity Targets. Japan: Nagoya.

Simboura, N., and others (2014). Benthic community indicators over a long period of monitoring (2000–2012) of the Saronikos Gulf, Greece, Eastern Mediterranean. *Environmental Monitoring and Assessment*, vol. 186, No. 6, pp. 3809–3821.

Snelgrove, P.V.R., and others (1997) The importance of marine sediment biodiversity in ecosystem processes, *Ambio*, vol. 26, pp. 578–583.

Officer, C.B., and others (1982). Benthic filter feeding: a natural eutrophication control. *Marine Ecology Progress Series*, vol. 9, pp. 203–210.

Stuart-Smith, Rick D., and others (2018). Ecosystem restructuring along the Great Barrier Reef following mass coral bleaching. *Nature*, vol. 560, pp. 92–96.

Tsiamis, Konstantinos, and others (2019). Non-indigenous species refined national baseline inventories: A synthesis in the context of the European Union's Marine Strategy Framework Directive. *Marine Pollution Bulletin*, vol. 145, pp. 429–435.

United Nations (2017). *The First Global Integrated Marine Assessment: World Ocean Assessment I*. Cambridge: Cambridge University Press.

Valiela, Ivan (1995). *Marine Ecological Processes*. New York, Springer-Verlag, second edition.

Vandepitte, Leen, and others (2018). A decade of the World Register of Marine Species–General insights and experiences from the Data Management Team: Where are we, what have we learned and how can we continue? *PloS One*, vol. 13, No. 4, e0194599.

Wang, H.J., and others (2018). The characteristics and changes of the species and quantity of macrobenthos in Yueqing Bay. *Marine Sciences*, vol. 6, pp. 78–87 (in Chinese with English abstract).

Warchol, Greg, and Michael Harrington (2016). Exploring the dynamics of South Africa's illegal abalone trade via routine activities theory. *Trends in Organized Crime*, vol. 19, No. 1, pp. 21–41.

WoRMS Editorial Board (2019). WoRMS – World Register of Marine Species. www.marinespecies.org. https://doi.org/10.14284/170.

Yesson, Chris, and others (2016). The impact of trawling on the epibenthic megafauna of the west Greenland shelf. *ICES Journal of Marine Science*, vol. 74, No. 3, pp. 866–876.

Zakharov Denis V., and others (2018). Diet of the snow crab in the Barents Sea and macrozoobenthic communities in the area of its distribution. *Trudy VNIRO*. vol. 172, pp. 70–90 (in Russian).

Zalota, Anna K., and others (2018). Development of snow crab *Chionoecetes opilio* (Crustacea: Decapoda: Oregonidae) invasion in the Kara Sea. *Polar Biology*, vol. 41, No. 10, pp. 1983–1994.

Addendum by the Group of Experts of the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socioeconomic Aspects

Status of pelagic invertebrates: cephalopods

Of the 750 species considered by the International Union for Conservation of Nature (IUCN), only one species is classified as Critically Endangered, two as Endangered and another two as Vulnerable, all of which are deep-sea umbrella octopuses (IUCN, 2020).

However, more than 419 species are considered Data Deficient, and they include many deep-sea dwellers (IUCN, 2020). Ten nautilus species were included in appendix II to the Convention on International Trade in Endangered Species of Wild Fauna and Flora in 2017 to regulate international trade therein.

Although information on many deep-sea dwellers is still scarce, recent advances in deep-sea research has increased understanding of the ecology and biology of deep-sea cephalopods. In the central Pacific Ocean, a rare observation of the mating and reproductive behaviours of the deep-sea squids *Chiroteuthis* spp. has been recorded (Vecchione, 2019). A specimen of giant squid, the largest species (up to 13 m) and one of the most enigmatic, was filmed in the Gulf of Mexico in 2019, which was only the second time ever that the species was recorded since it had been first observed in 2012. Analysis of the mitochondrial DNA of 43 specimens from the North Pacific Ocean, the Atlantic Ocean and Oceania supports the hypothesis that giant squids belong to a single species (*Architeuthis dux*) (Winkelmann and others, 2013). Ontogenetic changes in the feeding strategy of the vampire squid (*Vampyroteuthis infernalis*) have been established using stable isotope analyses (Golikov and others, 2019).

Recent work has identified a common multi-decadal increasing trend in the catch rates of dozens of cephalopods species with different biological and ecological strategies (demersal, benthopelagic and pelagic) in diverse oceanic regions (Doubleday and others, 2016). This proliferation has been attributed to their high adaptability and resilience to environmental fluctuations thanks to their rapid growth and flexible development. As an example, shoaling of the oxygen minimum zone in the California Current System has been thought to optimize feeding conditions for the Humboldt squid (*Dosidicus gigas*). This has allowed the species to thrive and expand its distribution northwards up to the Gulf of Alaska (Stewart and others, 2014). In the North Sea, a warming trend from the mid-1980s to the mid-2010s is thought to have been responsible for an increase in overall abundance of several squid species and in an northward expansion of their distribution (van der Kooij and others, 2016). Future warming of the Arctic Ocean may facilitate the trans-Arctic expansion of the European cuttlefish (*Sepia officinalis*) into North Canadian waters by 2300 (Xavier and others, 2016). In Australian waters, warming waters associated with a poleward extension of the Eastern Australian Current are facilitating the expansion of the distribution of the gloomy octopus (*Octopus tetricus*) (Ramos and others, 2018).

References

Doubleday, Zoë A., and others (2016). Global proliferation of cephalopods. *Current Biology*, vol. 26, No. 10, pp. R406–R407.

Golikov, Alexey V., and others (2019). The first global deep-sea stable isotope assessment reveals the unique trophic ecology of vampire squid *Vampyroteuthis infernalis* (Cephalopoda). *Scientific Reports*, vol. 9, No. 1, art. 19099. https://doi.org/10.1038/s41598-019-55719-1.

International Union for Conservation of Nature (IUCN) (2020). *The IUCN Red List of Threatened Species*. www.iucnredlist.org.

Ramos, Jorge E., and others (2018). Population genetic signatures of a climate change driven marine range extension. *Scientific Reports*, vol. 8,art. 9558. https://doi.org/10.1038/s41598-018-27351-y.

Stewart, Julia S., and others (2014). Combined climate- and prey-mediated range expansion of Humboldt squid (*Dosidicus gigas*), a large marine predator in the California current system. *Global Change Biology*, vol. 20, No. 6, pp. 1832–1843. https://doi.org/10.1111/gcb.12502.

Van der Kooij, Jeroen, and others (2016). Climate change and squid range expansion in the North Sea. *Journal of Biogeography*, vol. 43, No. 11, pp. 2285–2298. https://doi.org/10.1111/jbi.12847.

Vecchione, Michael (2019). ROV observations on reproduction by deep-sea cephalopods in the central Pacific Ocean. *Frontiers in Marine Science*, vol. 6, art. 403. https://doi.org/10.3389/fmars.2019.00403.

Winkelmann, Inger, and others (2013). Mitochondrial genome diversity and population structure of the giant squid *Architeuthis*: genetics sheds new light on one of the most enigmatic marine species. *Proceedings of the Royal Society B: Biological Sciences*, vol. 280, No. 1759, 20130273. https://doi.org/10.1098/rspb.2013.0273.

Xavier, José C., and others (2016). Climate change and polar range expansions: could cuttlefish cross the arctic? *Marine Biology*, vol. 163, No. 4, art. 78. https://doi.org/10.1007/s00227-016-2850-x.