Chapter 6C
Fishes

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Keynote points

- The mobilization of existing data and the development of tools and open, global repositories provide a global picture of the diversity of marine fishes, with 17,762 known species, including 238 species described since the first World Ocean Assessment (United Nations, 2017e).
- While knowledge of the biodiversity of marine fishes exceeds that of many other marine taxa, further improvements will be necessary not only in taxonomic and biosystematic infrastructure but also in the exploration and characterization of the oceans to achieve a complete inventory.
- More than half of the known marine fish species have had their conservation status assessed by the International Union for Conservation of Nature (IUCN), and approximately a third of those assessments having been conducted since the first Assessment.
- Of the fish species with conservation assessments, around 6 per cent of bony fishes, nearly 50 per cent of elasmobranchs, 10 per cent of chimaeras and both species of coelacanths are threatened or near threatened with extinction.
- Capacity for documenting and understanding marine fish diversity continues to grow, but significant gaps remain for certain ecosystem groups (e.g., mesopelagic fishes) and in predicting responses to multiple simultaneous external stressors.

1. Introduction

The present subchapter covers marine fish taxonomy, distribution, habitat and conservation status, emphasizing how the overall state of knowledge has changed since the first *World Ocean Assessment*. The consequences of changing fish diversity for humanity are briefly considered, and perspectives for specific regions are provided. The subchapter concludes with an outlook for fish biodiversity, including continuing gaps in knowledge and capacity. All 17,762 taxonomically valid species within the World Register of Marine Species (WoRMS) superclass Pisces (WoRMS, 2019) are considered, including bony fishes (class Actinopterygii, 16,503 species), sharks and rays (class Elasmobranchii, 1,202 species), chimaeras (class Holocephali, 55 species) and coelacanths (class Coelacanthi, 2 species).

The global biomass of marine fishes is approximately four times the total biomass of all birds and mammals (Bar-On and others, 2018), and fishes constitute an important part of marine biodiversity. Approximately 70 per cent of the marine fish biomass is comprised of mesopelagic fishes, although with wide estimate ranges, found in depths of 200–1,000 m (Irigoien and others, 2014, Hidalgo and Browman, 2019). Fishes occur throughout the world's oceans and in a wide range of depths. For example, the fish seen alive at the greatest depth is the snailfish *Pseudoliparis swirei*, formally described in 2017 and found in depths greater than 8,000 m in the Mariana Trench in the Pacific Ocean (Linley and others, 2016, Gerringer and others, 2017). Fishes play a key role in marine food webs as both predators and prey, often moving through food webs over the course of their lifetimes, such as from planktonic larvae into predatory adults. Fish biodiversity varies between habitats. Habitat affiliations in the Fishbase biodiversity information system for 17,246 species (97 per cent of all known species) show that most bony fishes are demersal or reef-associated, while most species of sharks and rays, chimaeras and coelacanths are demersal or bathydemersal (see table 1).

Fish biodiversity is changing, and fishes are sensitive to environmental changes caused by multiple external pressures (Comte and Olden, 2017) and to exploitation by fisheries (see chap. 15), which has important implications for human well-being (Food and Agriculture Organization of the United Nations (FAO), 2018). The first *Assessment* included chapters on the conservation challenges faced by the 1,088 species of sharks and other elasmobranchs (United Nations, 2017c) and the 25 species of tunas and billfishes (United Nations, 2017d). In addition, overall synthesis chapters revealed that fishes were among the best-known marine groups (United Nations, 2017a, b), with clear latitudinal and depth gradients in diversity. The mechanisms driving fish diversity are complex and include ecosystem stability and age, niche partitioning and predator-mediated dampening of dominance (Rabosky and others, 2018).

Overexploitation and habitat loss and degradation were recently identified as major threats to marine fish biodiversity, and while the impacts of climate change have become more apparent, pollution was not considered a significant threat (Arthington and others, 2016). Subsequently, evidence has emerged that scientific assessment and effective fisheries management can reverse the effects of overexploitation, leading to increases in abundance on average for well-managed stocks constituting half of the reported global fish catch, although overexploitation remains a significant threat in regions with less-developed fisheries management (Hilborn and others, 2020). The impacts of climate change and thermal stress on marine fishes, in particular coral reef fish communities, have become more severe (Robinson and others, 2019), while novel threats, for instance microplastic pollution, are now also attracting increased research interest, even though considerable uncertainty remains about their population-level effects (Villarrubia-Gómez and others, 2018).

Table 1
Number of valid marine species in each taxonomic class of fishes, according to the WoRMS taxonomy, in each broad habitat category

	Class							
	Actinopterygii		*Elasmobranchii*		*Holocephali*		*Coelacanthi*	
Habitat	Existing	Described since 2015	Existing	Described since 2015	Existing	Described since 2015	Existing	Described since 2015
Bathydemersal	1 785 (11%)	4	314 (26%)	2	38 (69%)	–	–	–
Demersal	5 691 (34%)	11	449 (37%)	5	11 (20%)	3	2 (100%)	–
Benthopelagic	1 422 (9%)	18	131 (11%)	13	4 (7%)	–	–	–
Bathypelagic	1 346 (8%)	3	33 (3%)	1	2 (4%)	–	–	–
Pelagic-neritic	807 (5%)	38	34 (3%)	10	–	–	–	–
Pelagic-oceanic	378 (2%)	1	83 (7%)	11	–	–	–	–
Reef-associated	4 618 (28%)	93	98 (8%)	1	–	–	–	–
Unknown	456 (3%)	22	60 (5%)	2	–	–	–	–
Total	16 503	190	1 202	45	55	3	2	–

Source: WoRMS Editorial Board (2019); Froese and Pauly (2019).

2. Documented change in the state of fish biodiversity

Documenting changes in fish biodiversity requires considering fish taxonomy, including the description of new species; spatial distribution, which can be assessed using occurrence records to reveal contractions or expansions in species ranges; and formal assessments of conservation status, to highlight species of conservation concern. Summarizing findings across higher taxonomic groups, and across groups of species occurring in similar habitat zones, is also necessary. Primary data sources used to quantify all those aspects of change are listed in table 2.

Table 2
Major types of global aggregations of data on marine fishes

Data type	Source	Reference
Taxonomy and systematics	World Register of Marine Species (WoRMS)	WoRMS Editorial Board, 2019;
	California Academy of Sciences	Van der Laan and others, 2019
	Eschmeyer's Catalog of Fishes	Fricke and others, 2020
Global occurrence data	Ocean Biodiversity Information System (OBIS)	OBIS, 2018
Habitat affinities	FishBase	Froese and Pauly, 2019
Conservation status	*IUCN Red List of Threatened Species*	IUCN, 2019

2.1. Taxonomy

Since 2015, 238 new marine fish species have been described and added to WoRMS (see table 1). Almost half (49 per cent) of the newly described bony fishes are reef-associated, whereas most of the newly described elasmobranchs are pelagic (see table 1). This rate of description is around 6 to 7 times lower than the one species per day described between 1999 and 2013 (United Nations, 2017a). This taxonomic effort is supplemented by recent phylogenetic studies of bony fishes (Rabosky and others, 2018) and of sharks, rays and chimaeras (Stein and others, 2018).

2.2. Occurrences

Fishes continue to be well represented in global occurrence databases, providing insight into distributions, biogeography and macroecological analyses. Collectively, the Ocean Biodiversity Information System (OBIS) (OBIS, 2018) includes 20,302,222 occurrence records for 15,101 marine fish species, with fishes making up more than a third of all occurrence records. Occurrence records are now available from OBIS for 85 per cent of bony fishes, 84 per cent of elasmobranchs, 78 per cent of chimaeras and one of the two coelacanth species. A total of 306,913 of those occurrence records have been added since the first Assessment, covering 4,099 (23 per cent) fish species, comprising 3,857 (23 per cent) bony fishes (for a total of 241,385 new occurrence records), 233 (19 per cent) sharks and rays (65,480 new records), eight (15 per cent) chimaeras (46 new records) and one of the two coelacanths (two new records). The first ever occurrences of 76 species (68 bony fishes and eight elasmobranchs) have been recorded in OBIS since 2015 (153 occurrence records in total). These species are primarily demersal (32 species) or reef-associated (13 species). Five of the 238 species added to WoRMS since the first Assessment already have occurrence records in OBIS.

2.3. Conservation status

Marine fishes are among the well-assessed marine taxonomic groups in terms of conservation status (Webb and Mindel, 2015). Fifty-three per cent (9,372 species) of all marine fishes have been assessed by IUCN in the 2019 Red List (IUCN, 2019)[1] and 44 per cent (7,756 species) have been assigned to a category other than Data Deficient. Thirty-two per cent (3,008 species) of all assessments of marine fishes have occurred since the first Assessment, in 2015. So far, as no marine fish species has been reassessed since the first Assessment, the IUCN Red List cannot yet be used to assess changes in the status of individual species. However, the proportion of species in each threat category is shown for each taxonomic class in table 3 and that for each habitat affiliation in table 4. Ecological and trait-based methods for predicting the conservation status of species categorized as Data Deficient suggest that, at least with regard to sharks and rays found in European waters, approximately half to two thirds of species in this category should also be considered as at risk of extinction (Walls and Dulvy, 2019). Recent evidence suggests that 24 per cent of the mean monthly space used by sharks falls under the footprint of pelagic longline fisheries and that pelagic sharks have limited spatial refuge from current levels of fishing effort in marine areas beyond national jurisdictions (Queiroz and others, 2019).

2.4. Advances in knowledge and capacity contributing to the evaluation of changes in state

The evaluation of changes in state since the first Assessment is made possible by new data from ongoing long-term monitoring programmes (e.g., international bottom trawl surveys by the International Council for the Exploration of the Sea (ICES)), contributions of fishery observers to scientific data collection, global compilations of fish stock assessments (e.g., the RAM Legacy Stock Assessment Database) and conservation assessments (e.g., the 2019 IUCN Red List), as well as improvements in technology allowing sampling in novel environments (Linley and others, 2016) and the monitoring of individual movements using satellite tagging (Curtis and others, 2018). Dramatic increases in knowledge of fish diversity have also been made possible by increased deep-water fishing (to 1,200 m) by commercial and research vessels, coupled with an increase in shallow-water sampling, enabling the discovery of many cryptic reef fish species in some regions (Gordon and others, 2010). Data infrastructure (e.g., WoRMS, OBIS and ICES data portal) providing the backbone for assessments has been supplemented by new analytical tools enabling users to interact programmatically with the data sources (Boettiger and others, 2012; Chamberlain, 2018; Chamberlain and Salmon, 2018; Provoost and Bosch, 2019; Millar and others, 2019). Those developments and tools have facilitated the use of marine fish data products as indicators of the status of marine ecosystems (ICES, 2018, 2019).

[1] Search focused on species in the classes Actinopterygii, Cephalaspidomorphi, Chondrichthyes, Myxini and Sarcopterygii with global scope, in the marine oceanic, marine deep benthic, marine intertidal, marine coastal and supratidal or marine neritic habitats, to ensure that all species within the World Register of Marine Species superclass Pisces were included (see www.iucnredlist.org/search?permalink=c53b-bf34-fec3-4549-8a83-d7630d2bc6bd).

Table 3

Number of marine fish species in each IUCN category by class

	Class											
	Actinopterygii			*Elasmobranchii*			*Holocephali*			*Coelacanthi*		
IUCN category	Pre-first Assessment	Post-first Assessment	Total	Pre-first Assessment	Post-first Assessment	Total	Pre-first Assessment	Post-first Assessment	Total	Pre-first Assessment	Post-first Assessment	Total
Least Concern	4 642	2 071	6 713 (80.6%)	117	201	318 (31.8%)	9	16	25 (54.3%)	-	-	-
Near Threatened	70	27	97 (1.2%)	85	22	107 (10.7%)	2	-	2 (4.3%)	-	-	-
Vulnerable	171	39	210 (2.5%)	80	27	107 (10.7%)	-	1	1 (2.2%)	1		1 (50%)
Endangered	45	18	63 (0.8%)	29	15	44 (4.4%)	-	-	-	-	-	-
Critically Endangered	25	2	27 (0.3%)	14	24	38 (3.8%)	-	-	-	1	-	1 (50%)
Extinct in the Wild or Extinct	2	-	2 (0.02%)	-	-	-	-	-	-	-	-	-
Data Deficient	746	467	1 213 (14.6%)	310	75	385 (38.5%)	15	3	18 (39.1%)	-	-	-
Total	5 701 (34.5%)	2 624 (15.9%)	8 325	635 (52.5%)	364 (30.1%)	999	26 (47.3%)	20 (36.4%)	46	2 (100%)	0 (0%)	2

Note: “Pre-first Assessment” indicates the number of species most recently assessed before 2015, and “Post-first Assessment” the number of species assessed since 2015. Also shown are the total number of species in each IUCN category for each class and the percentage of all assessed species in each IUCN category for each class. The last row shows the total number of species assessed pre- and post-first Assessment in each class, and the percentage of all species in that class that have been assessed.

Table 4
Number of marine fish species in each IUCN category by habitat affiliation

	Not Evaluated		Data Deficient		Not Threatened		Threatened	
	Number of species	Percentage of all known species	Number of species	Percentage of species assessed by IUCN	Number of species	Percentage of species assessed by IUCN	Number of species	Percentage of species assessed by IUCN
Bathydemersal	1 325	61.9	285	34.9	491	60.1	41	5.0
Demersal	3 060	49.7	617	19.9	2 169	69.9	317	10.2
Benthopelagic	936	60.0	124	19.8	440	70.4	61	9.8
Bathypelagic	594	42.7	140	17.6	452	81.9	4	0.5
Pelagic-neritic	351	41.6	120	24.4	335	68.1	37	7.5
Pelagic-oceanic	187	40.5	41	14.9	202	73.5	32	11.6
Reef-associated	1 561	33.0	262	8.3	2 712	85.5	198	6.2
Unknown	425	82.2	27	29.3	55	59.8	10	10.9

Note: The percentages of species categorized as “Not Evaluated” are the percentages of all known species with a given habitat affiliation that have not been assessed by IUCN. Percentages in the other columns are percentages of species assessed by IUCN in each category. The IUCN categories Least Concern and Lower Risk/Least Concern are combined under “Not Threatened”, and the categories Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild and Extinct are combined under “Threatened”.

3. Consequences of biodiversity change on human communities, economies and well-being

Changes in fish biodiversity have direct and immediate consequences for human communities, economies and well-being through their impacts on commercial, recreational and subsistence fisheries, as well as on alternative sources of income derived from marine ecosystems, including tourism (FAO, 2018). Fishes are integral to the achievement of Sustainable Development Goal 14 of conserving and sustainably using marine resources,[2] with several indicators relating directly to the role that fishes play in sustainable food provision (see chap. 15). Improved knowledge of the distribution and abundance of marine fishes, in particular, is key to monitoring progress toward target 14.4 (effectively regulate harvesting). Increasing the economic benefits to small island developing States and least developed countries through tourism (target 14.7) will involve understanding the distribution and status of charismatic fish species, such as manta rays (Kessel and others, 2017) or fish assemblages, such as coral reef fishes (Wabnitz and others, 2018).

[2] See General Assembly resolution 70/1.

4. Key region-specific changes and consequences

4.1. North Atlantic Ocean

In the North Atlantic and adjacent areas, pressure on fish stocks shows an overall downward trend over the period 2003–2017, with the median fishing mortality stabilized at 1.0. The pressure indicator (F/Fmsy) for the Mediterranean and the Black Sea has remained at 2.2. The number of stocks within safe biological limits has almost doubled, from 15 in 2003 to 29 in 2017, with the largest increase in the Bay of Biscay and the Iberian waters – from 2 to 8 stocks. The overall biomass volume has continued to develop positively, increasing by around 36 per cent. In the Mediterranean and the Black Sea, the 2016 spawning stock biomass showed no significant increase compared with 2003. The North-West Atlantic saw a marked change in fish community structure with the collapse of cod and mackerel stocks as a result of overfishing (Shelton and Sinclair, 2008; Van Beveren and others, 2020).

In the Baltic Sea, gradual long-term trends, rather than abrupt changes in functional diversity and multi-trait community composition, were observed between 1971 and 2013 (Törnroos and others, 2018). There are three sub-assemblages along a strong west-east salinity gradient, with low functional redundancy in the Baltic Proper compared with other sub-areas, suggesting an ecosystem more susceptible to external pressures (Frelat and others, 2018). In the North Sea, taxonomic and trait-based indicators provide new evidence of fish assemblage structure and highlight the multifaceted effects of drivers responsible for those changes. Specifically, the central North Sea displayed a decrease in community size structure linked to changes in fishing, and the Norwegian trench region displayed an increase in community size structure primarily linked to climate change, while no change was observed along the eastern Scottish coast where the community size structure was most strongly associated with net primary production (Marshall and others, 2016). In the Mediterranean, the dynamics of small and medium pelagic fish populations exhibit synchrony with climate variability: while the North Atlantic Oscillation is affecting their dynamics in the western and central Mediterranean, anchovy and sardine populations follow the signal of the Atlantic Multidecadal Oscillation in the eastern and central Mediterranean. Thus, there are strong subregional patterns in the temporal dynamics of pelagic fish in the Mediterranean (Tsikliras and others, 2019).

4.2. South Atlantic Ocean

The wider Caribbean region is highly biodiverse and an important region of fish endemism, with approximately 50 per cent of its bony fishes occurring nowhere else (Linardich and others, 2017). Diverse oceanographic and hydrographic features yield an array of subtropical and tropical habitats, including 8 per cent of the world's coral reefs and 6 per cent of seamounts (Oxenford and Monnereau, 2018). Fish biodiversity is negatively affected by overfishing, habitat destruction (in particular of coral reefs) and climate change (Jackson and others, 2014; Oxenford and Monnereau, 2018). Several large-bodied fish species have become commercially extinct or critically endangered (Linardich and others, 2017). The reduction in fish biodiversity is affecting the functioning of Caribbean coral reefs (Lefcheck and others, 2019), with socioeconomic consequences, especially for small island developing States, where up to 22 per cent of the workforce is employed in the fishery sector (Edwards and Yarde, 2019).

A significant emerging phenomenon is the unprecedented bloom across the equatorial Atlantic of pelagic *Sargassum* seaweed, which has been advecting into the Caribbean Sea since 2011 (Wang and others, 2019). This has had a negative impact on critical fish habitats and associated fish biodiversity nearshore (van Tussenbroek and others, 2017; Rodríguez-Martínez and others, 2019), but has had positive effects on some pelagic reef-associated species, the populations of which have increased and are now supporting fisheries (e.g., the yellow jack *Carangoides bartholomaei* and the almaco jack *Seriola rivoliana*) (Ramlogan and others, 2017; Monnereau and Oxenford, 2017). Landings of offshore pelagic species appear to have been disrupted by the presence of *Sargassum*, with some being more readily available, but often as small juveniles (e.g., the dolphinfish *Coryphaena hippurus*), while others (e.g., the flying fish *Hirundichthys affinis*) are more difficult to catch (Oxenford and others, 2019; Caribbean Regional Fisheries Mechanism-Japan International Cooperation Agency, 2019).

4.3. North Pacific Ocean

The North Pacific Ocean, extending from arctic to tropical waters, has the highest fish species diversity in the world, with more than 6,000 species. This rich diversity is derived from and supported by strong water currents flowing northwards and southwards along the north-western continental shelf. Such currents have functioned both to transfer fishes and to isolate fish populations, thereby facilitating speciation (Motomura, 2019). The northern region is a major fishing ground, contributing to about 30 per cent of global catches, mainly targeting the pollack, tunas, sardines and anchovies. The southern region includes the northern part of the Coral Triangle, identified as a marine biodiversity hotspot, and has a higher species richness of shore fishes than any other large marine areas on the globe (Roberts and others, 2002). Most fishes in the southern part are associated with coral reefs and have seen population declines as a result of intense fishing pressure and habitat degradation (Nañola and others, 2011).

4.4. South Pacific Ocean

The South Pacific Ocean includes several highly biodiverse tropical, subtropical and temperate marine ecosystems, modulated directly by the El Niño Southern Oscillation and monsoons. There is high inter-annual variability of primary production that leads to a rich diversity of marine fishes, including reef fishes, pelagic species and highly migratory species (e.g., tuna, sharks and manta rays). Fish biodiversity in this region is affected by fishing (including by-catch) of small pelagics, sharks and tuna, as well as by climate change and pollution, which threaten nursery habitats and drive species from tropical to temperate waters. The destruction of strategic habitats, such as mangroves, can change the distribution and abundance of fish species that use those areas for reproduction and feeding.

Areas of the South-West Pacific that have been explored, including ocean ridges and seamount chains, support a rich marine fish diversity (Clark and Roberts, 2008; Roberts and others, 2015). The fish faunas of the tropical islands of Melanesia and Polynesia in the northern South-West Pacific are predominantly from the Indo-West Pacific in nature, with high diversity but relatively low levels of endemism. In contrast, New Caledonia (France) is a centre of fish endemism, with 107 of 2,341 recorded species endemic to the exclusive economic zone (Fricke and others, 2011; 2015). Off the coast of New Zealand, the number of known marine fish species has grown from around 1,000 species in 1993 to more than 1,294 in 2019 (Roberts and Paulin, 1997; Roberts and others, 2015, 2019), with 22 per cent endemic to the New Zealand region and half of the additional species new to science. Australia is positioned south-west of the aforementioned tropical archipelagos, spans the junctions of two major oceans and is home to some 2,000 known marine fish species.

5. Outlook

Positive outlooks for fish biodiversity come from the evidence that individual fish populations respond positively to effective fisheries management (Hilborn and others, 2020) and that fish diversity and biomass increase within effective marine protected areas (Sala and Giakoumi, 2017). However, the global extinction of the smooth handfish *Sympterichthys unipennis* (Last and others, 2020) is a reminder that fish biodiversity continues to face significant threats as well. Both positive and negative outcomes are known because fishes continue to be among the most systematically studied and monitored components of marine ecosystems, mostly because of their economic value. Nonetheless, considerable fish diversity remains to be discovered: expert estimates indicate that at least another 700 fish species (approximately a 50 per cent increase over the number of currently known species) are yet to be described from the New Zealand exclusive economic zone and extended continental shelf alone (Gordon and others, 2010; Roberts and others, 2019). Further increase in capacity in taxonomy and biosystematics (Taxonomy Decadal Plan Working Group, 2018) and the integration of data from existing biodiversity collections (Nelson and others, 2015) and other sources (Edgar and others, 2016) would pave the way for more comprehensive, synthetic analyses of fish biodiversity over the near to medium term. In addition to improving our understanding of fish biodiversity, improved estimates of fish biomass are needed for some ocean zones, such as the pelagic zone. While it is estimated that mesopelagic fishes dominate global fish biomass, estimates of their biomass span several orders of magnitude and, therefore, the exact contribution that this group makes to global patterns remains poorly understood (Irigoien and others, 2014; Hidalgo and Browman, 2019). In addition, while there are no current estimates of species richness or biomass of bathypelagic fishes, which reside in the world's largest environment (in terms of volume), it is highly likely that those fishes constitute a large portion of global fish biomass (Sutton and others, 2017). Since the first Assessment, the disposal of deep-sea mining water after ore removal has emerged as a significant threat to bathypelagic fishes (Drazen and others, 2019). Key knowledge and capacity gaps in fish biodiversity are summarized in table 5.

Table 5
Key gaps in the understanding of the biodiversity of marine fishes

Knowledge and capacity gaps	Examples of remedial steps taken to address the gaps
Taxonomic and biosystematics infrastructure and capacity	National and international plans to support and develop core taxonomic activities, workforce and infrastructure (e.g., Taxonomy Decadal Plan Working Group, 2018)
Mobilization of existing data into open, global repositories	Historical data rescue, digitization of museum specimens and historical biodiversity literature (e.g., Faulwetter and others, 2016)
Understanding of mesopelagic and deep-sea fish diversity	More and better sampling regimes, employing novel technologies (e.g., Linley and others, 2016; Hidalgo and Browman, 2019)
Response of fishes to multiple simultaneous stressors	Better linking of relevant data across disciplines (e.g., Hodgson and others, 2019)

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