Section 4

Subchapter 4D

Fishes

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Key points

- The accelerating impacts of climate change continue to affect fish life histories and populations globally.
- Since the publication of the second *World Ocean Assessment*, 787 new species of fish have been added to the FishBase database, which contains a total of 35,002 species described.
- New or improved research techniques, such as satellite tagging, video cameras, molecular genetic work are helping to advancing understanding of fish diversity, behaviour and biology.

1. Introduction

The present subchapter provides an update on taxonomy, biology, distribution, habitat and conservation status of bony (Osteichthyes) and non-bony (Chondrichthyes and Agnatha) fish. It is focused on the period 2018 to 2023, on what changes have occurred globally and regionally in terms of production and diversity and on new information that has become available since the publication of the second *World Ocean Assessment*. The present subchapter will also contain a discussion of remaining key knowledge gaps, capacity changes to better understand fish and whether any new gaps have come to light.

Other overlapping or complementary information relevant to fishes, including changes to fish biomass, is provided in the subchapters on large-and small-scale fisheries (subsect. 5A, subchaps. 1A and 1B); recreational fishing (subsect. 5A, chap. 2); climate change (sect. 4, chap. 1); specific fish habitats (sect. 4, chap. 5, various subchaps.); physical conditions and cumulative pressures (sect. 4, chaps. 3 and 6); and the socioeconomic importance of fish and how fish fit into One Health (subsects. 5A and 5B, various chapters).

2. Environmental change since the second *World Ocean Assessment*

Fish biomass is strongly affected by environmental, anthropogenic, global and regional pressures. Climate change and the resulting impacts on the marine environment (see sect. 4, chaps. 1 and 3) are having a significant effect on fish populations globally, from positive expansion and growth in new areas (e.g. polar and high latitude areas) to significant declines in other areas (Nagelkerken and others, 2023; Blanchard and Novaglio, 2024). These pressures also affect fish biology and growth, fish behaviour, the timing of spawning and migration, and natural mortality (Nagelkerken and others, 2023). Many regions are affected by the removal of fish by poorly managed fishing and fisheries (subsect. 5A, chaps. 1A, 1B and 2), including through habitat damage from fishing gear, illegal unreported and unregulated fishing and the arrival or introduction of alien species.

The latest reports of the Intergovernmental Panel on Climate Change (IPCC) and the Food and Agriculture Organization of the United Nations (FAO) have projected range shifts among marine fish, suggesting latitudinal changes in fish biomass and decreasing biodiversity (Cooley and others, 2022). Most areas in lower latitudes are projected to have decreasing fish biomass into the future due to unfavourably warm ocean temperatures, while high latitude areas are expected to have increased fish biomass as a result of more favourable warm temperatures (Blanchard and Novaglio, 2024).

Climate change is also increasing spatiotemporal life history mismatches, such as in larval access to food sources (Nagelkerken and others, 2023). Non-climate, anthropogenic factors amplify the impacts of climate change (Gissi and others, 2021).

The Agreement on Marine Biological Diversity of Areas beyond National Jurisdiction may support habitat protection and management of fishing in high seas areas, which will in turn support fish populations and biodiversity (Wang 2025; Santos and others, 2022).

Continuous research and documentation of the spatial biodiversity and International Union for Conservation of Nature (IUCN) status of fish has advanced in recent years (tables 1 and 2). A total of 787 new species have been described in FishBase (table 1) and 6,062 have been assessed by IUCN (table 2) since 2019.

Table 1

Number of described marine species of fishes in different habitats across taxonomic class, including species identified since 2019

Habitat	**Class**								
	Teleostei		**Elasmobranchii**		**Holocephali**		**Coelacanthi**		
	Described since 2019	**All species (2024)**	**Described since 2019**	**All species (2024)**	**Described since 2019**	**All species (2024)**	**Described since 2019**	**All species (2024)**	**Total species identified, by habitat (percentage of all identified fish)**
Bathydemersal	38	1 900	9	327	2	52	–	–	**2 279 (6.5)**
Bathypelagic	14	1 399	1	36	–	–	–	2	**1 437 (4.1)**
Benthopelagic	234	11 546	5	169	–	–	–	–	**11 715 (33.5)**
Demersal	225	11 448	19	480	–	3	–	–	**11 931 (34.1)**
Pelagic	48	1 196	–	1	–	–			**1 197 (3.4)**
Pelagic-neritic	48	917	1	36	–	–	–	–	**953 (2.7)**
Pelagic-oceanic	9	406	3	86	–	–	–	–	**492 (1.4)**
Reef-associated	130	4 890	1	108	–	–	–	–	**4 998 (14.3)**

Total **(percentage of all identified species)**	**746** –	**33 702** **(96.3)**	**39** –	**1243** **(3.6)**	**2** –	**55** **(0.2)**	**0** –	**2** **(<0.1)**	**35 002**

Source: Prepared by the writing team.

Table 2

Number of marine fish species in each International Union for Conservation of Nature category across taxonomic classes, including the number newly assessed since the drafting of the second *World Ocean Assessment* (2019)

IUCN Category	CLASS								
	Teleostei		Elasmobranchii		Holocephali		Coelacanthi		All
	Assessed since previous *World Ocean Assessment* (2019)	Total (2024)	Assessed since previous *World Ocean Assessment* (2019)	Total (2024)	Assessed since previous *World Ocean Assessment* (2019)	Total (2024)	Assessed since previous *World Ocean Assessment* (2019)	Total (2024)	Total fish species by IUCN category (percentage of all IUCN-assessed species)
Least concern	3 685	9 262	345	503	20	35	–	–	9 800 (74.2)
Near threatened	37	113	102	119	4	4	–	–	236 (1.8)
Vulnerable	63	235	160	171	4	4	–	1	411 (3.1)
Endangered	43	95	114	124	–	–	–	–	219 (1.7)
Critically endangered	10	21	88	92	–	–	–	1	114 (0.9)
Extinct in the wild or extinct	–	1	1	1	–	–	–	–	2 (< 0.1)
Data deficient	1 311	2 281	66	137	9	10	–	–	2 418 (18.4)
Total	**5 149**	**12 008**	**876**	**1 147**	**37**	**53**	**0**	**2**	**13 210 (100)**

Source: Prepared by the writing team.

3. Region-specific changes

Arctic Ocean

Arctic fish populations are experiencing significant shifts in spatial distribution, population dynamics and community composition due to climate change, overfishing and environmental changes. The warming Arctic Ocean is driving the poleward migration of sub-Arctic species such as Atlantic cod (*Gadus morhua*), altering the composition of marine ecosystems (Gordó-Vilaseca and others, 2024). Concurrently, the retreat of sea ice is enabling increased fishing pressure in previously inaccessible areas, raising concerns for vulnerable species such as polar cod (*Boreogadus saida*) (Bryndum-Buchholz and others, 2019; Steiner and others, 2021). Invasive species and the expansion of commercial fisheries are compounding the pressures on endemic Arctic fish populations (Ogorelec and others, 2022). The cumulative effects of these changes threaten the sustainability of key species and the broader Arctic marine food web, necessitating adaptive management strategies (Bluemel and others, 2022; Nilsen and others, 2022). Recent studies emphasize the importance of implementing spatial fisheries management and establishing marine protected areas (MPAs) to mitigate these impacts (Phillips and others, 2025), including through meaningful partnerships and collaborations with local and Indigenous Arctic communities. These measures are crucial for preserving Arctic biodiversity and ensuring the long-term viability of commercial fish stocks in the region (Gordó-Vilaseca and others, 2024).

North Atlantic Ocean, Baltic Sea and North Sea

Climate change is expected to increasingly affect fish populations in the northern oceanic waters. Atlantic water temperatures are projected to increase, reducing sea ice extent and boosting primary productivity, influencing distribution, growth rates, spawning locations and early-stage mortality of fish species (Gordó-Vilaseca and others, 2024). There has been a shift in the ranges of North Atlantic species moving eastward and warmer-water species migrating north, leading to an enrichment of Arctic and sub-Arctic marine fauna (Gordó-Vilaseca and others, 2023). These waters face decreasing biomass and biodiversity with respect to traditionally high-latitude sedentary species (Gordó-Vilaseca and others, 2024). In more southern areas (such as the Canary Islands region), there is a tropicalization of fish populations, where many new species of tropical origin are increasingly being reported (Bañón and others, 2024; Falcón and others, 2023), and northward expansion of common species off north-western Africa (such as *Scomber colias* and *Sardinella aurita*) have been reported (Amenzoui and Baali, 2018; Blanchet and others, 2019; International Council for the Exploration of the Sea (ICES), 2021). The patterns of change are highly variable from location to location depending on the rapidity of change; for example, rapidly warming locations develop more rapidly growing fish and slow-changing areas have more slow-growing species (Receveur and others, 2024).

Mediterranean Sea and Black Sea

The Mediterranean Sea is a hotspot of cumulative climate change impacts and is subject to increasing heat waves, extreme events, seasonal warming and changes in currents and degree of stratification (Hidalgo and others, 2018). These developments are causing changes to fish ranges, spawning seasons (Moltó and others, 2024), population structures, dispersal patterns, the structure of food webs and the composition of communities, as well as the increasing presence of non-endemic species (Zenetos and Galanidi, 2020; Yapici, 2021).

There is strong biogeographical structuring of populations, with many examples in northern areas showing northward displacements (e.g. Sbragaglia and others, 2020), but fish populations are also responding unexpectedly to change in more intermediate latitudes with southward distributional shifts of demersal species (Sanz-Martín and others, 2024; Sbragaglia and others, 2020). There is an east-west gradient in warming and increasing immigration of species from the Red Sea and Indian Ocean, making the eastern Mediterranean a hotspot of invasive species (Öztürk, 2021).

Anthropogenic disasters, such as the explosion of the Kakhovka Dam in 2023, are expected to significantly worsen the ecological state of the Black Sea (Minicheva and others, 2023; Vyshnevskyi and others, 2023), although some large pelagic species (bluefin tuna and swordfish) are slowly returning to the Black Sea for unclear reasons (Di Natale and others, 2019; Di Natale, 2021).

South Atlantic Ocean and wider Caribbean

The South Atlantic Ocean and Caribbean Sea have undergone significant changes since 2018, including warming trends and salinity alterations (Chidichimo and others, 2023; Craig and others, 2021) as well as increased extreme events (Gramcianinov and others, 2023). These changes are having significant effects on marine ecosystems, including shifts in the distribution of species (e.g. tropical species, tuna) and impacts on biodiversity (Perez and Sant'Ana, 2022; Townhill and others, 2021; Craig and others, 2021). Coral reefs in some areas have been dying from disease and bleaching, resulting in the loss of reef fish habitat and changes in fish communities (Swaminathan and others, 2024; Reimer and others, 2024).

Indian Ocean

The Indian Ocean region is known for its exceptional biodiversity, driven by a unique monsoon system that drives upwelling, nutrient-rich currents and high primary productivity (Marsac and others, 2024). Estimates of fish diversity report over 3,600 species of coastal fishes in the western Indian Ocean (Bullock and others, 2021). The region is also increasingly experiencing rapid sea surface warming, leading to deoxygenation in some coastal areas of the Arabian Sea and the Bay of Bengal (Dalpadado and others, 2023), contributing to biodiversity loss. Large fish biomass reductions (over 50%) have been projected, with tunas being particularly affected (Wilson and others, 2021), although bluefin tuna have expanded their distribution range (Di Natale and others, 2022). Hotspots of threatened species have been identified in the southern Red Sea and the southern coast of India, with more than 90% of such species being affected by targeted fisheries, caught as by-catch, and affected by illegal, unreported, and unregulated fishing activities, which is particularly the case for valuable species, including sharks and tunas (Bullock and others, 2021, Worm and others, 2024).

North Pacific Ocean

The North Pacific features the highest number of fish species and the most genetic diversity globally, owing to its large latitudinal scale and diversity in marine habitats and ocean currents. The area includes arctic to tropical waters and highly biodiverse areas such as the Coral Triangle and oceanic islands and archipelagos (Manel and others, 2020; Miller and others, 2018; Tittensor and others, 2010). Mesophotic zones around tropical coral reefs harbour high fish diversity (Pinheiro and others, 2019).

Climate change is increasing poleward shifts in teleost and elasmobranch distributions and fish invasions and extinctions, particularly in oceanic islands (Cruz and others, 2024; Hastings and others, 2020; Tanaka and others, 2021). Increasingly frequent and intense marine heatwaves are likely to drive marine fish extinctions in Pacific islands, potentially affecting future food security (Asch and others, 2018; Jacox and others, 2020; Smale and others, 2019; Oliver and others, 2021). The effects of climate change, El Niño and La Niña are expected to redistribute tuna species (Lehodey and Senina, 2018).

South Pacific Ocean

The diversity of fish in the South Pacific, including tropical, subtropical and temperate regions, faces increasing threats from climate change, pollution and overexploitation (Clarke and others, 2020; Dulvy and others, 2021; O’Hara and others, 2021). Warming oceans are shifting distributions poleward and are predicted to alter patterns of migration and invasion and potentially cause extinctions (Rodriguez-Burgos and others, 2022; Clarke and others, 2020). The El Niño/Southern Oscillation affects fish diversity and distribution and is forecast to increase in frequency and intensity (Oliver and others, 2021). Marine heatwaves in 2023/24 triggered the fourth global coral bleaching event, spreading across the Australian Great Barrier Reef and South Pacific islands, but the impacts on fish biodiversity are still unclear (Reimer and others, 2024). Microplastic ingestion in marine fish, including commercial species in South Pacific coastal regions and oceanic islands, is rising, but population-level impacts have not been assessed (Muñoz-Pérez and others, 2023; Savoca and others, 2021; Wootton and others, 2021).

Southern Ocean

Antarctic fish populations are increasingly affected by climate change, marine heatwaves, fishing pressures and environmental shifts. Warming waters in regions such as the Antarctic Peninsula are disrupting reproductive cycles of species such as black rockcod, (*Notothenia coriiceps*) and causing habitat loss for ice-dependent species such as emerald rockcod (*Trematomus bernacchii*) and yellowfin icefish (*Chaenocephalus aceratus*) (Novillo and others, 2024). Reduced sea ice is severely affecting Antarctic silverfish (*Pleuragramma antarcticum*), a key prey species, especially along the western Antarctic Peninsula (Caccavo and others, 2021). Fishing pressures in areas such as the Ross Sea exacerbates these challenges, particularly for top predators such as Antarctic toothfish (*Dissostichus mawsoni*), which play a critical role in the ecosystem (Caccavo and others, 2021). Recent studies highlight the vulnerability of Antarctic lanternfish (*Electrona antarctica*), as changes in prey availability and oceanographic conditions alter their feeding strategies (Duan and others, 2024). Adaptive management strategies, such as those implemented through the Commission for the Conservation of Antarctic Marine Living Resources, are crucial to mitigating these impacts and preserving Antarctic marine ecosystems (Corso and others, 2024). Conservation efforts are critical as climate change effects intensify, which will in turn increase the need for continued research and monitoring (Greco, 2022).

4. Key remaining knowledge and capacity gaps

Key gaps in the current understanding of marine fish and steps to reduce those gaps are listed in tables 3 and 4 below.

Table 3

Key gaps in the second *World Ocean Assessment* and recent efforts to reduce those gaps

Knowledge and capacity gaps	Recent steps taken to address the gaps
Taxonomic and biosystematics infrastructure and capacity	The FAO ecosystem approach to fisheries (EAF)-Nansen Programme is providing a ship and research support staff to train students and scientists in coastal developing countries.
Mobilization of existing data into open global repositories	Creation of the Global Biodiversity Information Facility (GBIF) (GBIF, 2024) to obtain data from samples not examined (e.g. from scientific surveys).
Understanding of mesopelagic and deep-sea fish diversity	European marine strategies include implementation of programmes for monitoring of deep-sea habitats.
Cumulative stressors on fish	In resolution 7.2 of the Conference of the Parties to the Convention on the Conservation of Migratory Species of Wild Animals (Rev.COP14), cumulative stressors on migratory species, including fish, are identified and the need for action is emphasized in that regard.

Source: Prepared by the writing team.

Table 4

New gaps identified since the publication of the second *World Ocean Assessment*

New knowledge and capacity gaps	Steps taken to address the gaps
Detection of illegal, unreported and unregulated (IUU) fishing	Improved satellite monitoring of vessels (e.g. by Global Fishing Watch).
Satellite surveillance	Satellite monitoring has improved for the tracking of illegal fishing, pollution and maritime traffic, providing real-time data (Matley and others, 2024; Paolo and others, 2024). Electronic devices (e.g. satellite tags) have improved the understanding of life cycles and migratory movements (Renshaw and others, 2023).
Spatial dimension of stock assessments	Improved assessment and management of transboundary and migratory stocks (e.g. FAO 2020; Hidalgo and others, 2024). Increased application of best-practice spatial stock assessment (Goethel and others, 2023, Berger and others, 2024). This implies

	certain improvements in data collection, data management and data sharing between jurisdictions (Cope and others 2024).
Understanding of life history traits at regional scales	Harmonization of life history research and better understanding of phenotypic and phenological plasticity and spatial variation (Zarco-Perello and others, 2022; Carbonara and others, 2019; Follesa and others, 2019; Vitale and others, 2019).
Fish populations	Baited remote underwater video systems (BRUVS), hydro-acoustics (Kang and others, 2024) and genomics have improved the understanding of spatial dynamics of global fish communities, biodiversity and habitat associations (Leonetti and others, 2024; Mateos-Molina and others, 2024; Moore and others, 2020; Orozco-Ruiz and others, 2023; Vaux and others, 2021). More accessible, improved data and modelling are increasingly informing the understanding of spatial and temporal trends in fish biomass (e.g. FishGlob initiative; Maureaud and others, 2021, Receveur, 2024; Blanchard and Novaglio, 2024; Fredston and others, 2023; Payne 2023; Fuchs and others, 2024).
Threatened species protection	There are area-based conservation measures being applied globally for threatened fish species, especially elasmobranchs. Important shark and ray areas are being identified through IUCN. Since the publication of the first *World Ocean Assessment*, the identification of Important Shark and Ray Areas by IUCN has advanced significantly. These are defined as spatially discrete habitats critical for the survival of sharks and rays, based on science-driven criteria aligned with global conservation frameworks. As of 2025, Such Areas have been identified in regions such as the Mediterranean, the western Indian Ocean, the South Atlantic and the South Pacific, with ongoing efforts elsewhere. The Important Shark and Ray Areas process informs spatial planning, MPA design and other conservation measures to protect elasmobranch biodiversity amid environmental change (see https://sharkrayareas.org/about-isras/). New global approaches have been developed to identify essential habitats for elasmobranchs to guide spatial management (Notarbartolo di Sciara, 2021). In Brazil, especially in Rio de Janeiro, pioneering studies have been carried out on shark migration and behaviour to support conservation measures in the South Atlantic (Andrzejaczek and others, 2022; Queiroz and others, 2019, 2021a, 2021b).

	Globally, action plans are being developed through the Convention on the Conservation of Migratory Species of Wild Animals to support elasmobranch populations (e.g. of the Mediterranean angelshark; see Cancino, 2024). The Convention also provides measures (resolution 14.5) for preventing vessel strikes on marine megafauna (e.g. whale sharks) (Womersley and others, 2024).
Fish behaviour and communication	Developing understanding of intraspecific communication in fish (Looby and others, 2022; Valastro and others, 2024).
Microplastic pollution	There is increasing evidence for the ingestion of microplastics and nanoplastics by fish, but the impacts on biomass and diversity remain unknown (Wootton and others, 2021; Jonathan and others, 2021; Savoca and others, 2021; Tekman and others, 2022).
Deep scattering layers	Deep scattering layers provide an important link between shallow water and deepwater areas (Peña, 2024).
Understanding of biotic perturbations of the water column	High spatial resolution acoustic and hydrological data (Fernández-Castro and others, 2022).

Source: Prepared by the writing team.

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References

Amenzoui, Khadija, and Baali Ayoub (2018). Biological parameters of *Sardinella aurita* (Valenciennes, 1847) exploited in the Dakhla zone (South Atlantic Morocco). International Journal of Scientific and Engineering Research, vol. 9, No. 8, pp. 85–90.

Andrzejaczek, Samantha, and others (2022). Diving into the vertical dimension of elasmobranch movement ecology. Science Advances (AAAS), vol. 8, No. 33, eabo1754.

Asch, Rebecca G., and others (2018). Future marine ecosystem drivers, biodiversity, and fisheries maximum catch potential in Pacific Island countries and territories under climate change. Marine Policy, vol. 88, pp. 285–294.

Bañón, Rafael, and others (2024). Tropicalization of fish fauna of Galician coastal waters, in the NW Iberian upwelling system. Regional Studies in Marine Science, vol. 70, art. 103369.

Berger, Aaron, M., and others (2024). Synthesizing the spatial functionality of contemporary stock assessment software to identify future needs for next generation assessment platforms. Fisheries Research, vol. 275, art. 107008.

Blanchet, Marie-Anne, and others (2019). How vulnerable is the European seafood production to climate warming? Fisheries Research, vol. 209, pp. 251–258.

Bluemel, Joanna, and others (2022). Decline in Atlantic wolffish *Anarhichas lupus* in the North Sea: Impacts of fishing pressure and climate change. Journal of Fish Biology, vol. 100, No. 1, pp. 253–267.

Blanchard, Julia, L., and Novaglio, Camilla, eds. (2024). Climate change risks to marine ecosystems and fisheries – Projections to 2100 from the Fisheries and Marine Ecosystem Model Intercomparison Project. FAO Fisheries and Aquaculture Technical Paper, No. 707, Rome: FAO.

Bryndum-Buchholz, Andrea, and others (2019). Twenty-first-century climate change impacts on marine animal biomass and ecosystem structure across ocean basins. Global Change Biology, vol. 25, No. 2, pp. 459–472.

Bullock, Robert and others (2021). The conservation status of marine biodiversity of the Western Indian Ocean. International Union for the Conservation of Nature, Gland, IUCN.

Caccavo, Jilda Alicia, and others (2021). Productivity and change in fish and squid in the Southern Ocean. Frontiers in Ecology and Evolution, vol. 9.

Cancino, X. (2024). CMS Single Species Action Plan for Angelshark (Squatina squatina) in the Mediterranean Sea, Convention on the Conservation of Migratory Species of Wild Animals. Germany, 2024. COI: 20.500.12592/6t1g6td.

Carbonara, Pierluigi, and Follesa, Maria Cristina, eds. (2019). Handbook on fish age determination: a Mediterranean experience. Studies and Reviews. General Fisheries Commission for the Mediterranean, FAO, Rome, No. 98, pp. 1–192.

Chidichimo, María Paz, P., and others (2023). Energetic overturning flows, dynamic interocean exchanges, and ocean warming observed in the South Atlantic. Communications Earth and Environment, vol. 4, No. 10.

Clarke, Tayler M., and others (2020). Climate change impacts on living marine resources in the Eastern Tropical Pacific. Diversity and Distributions, vol. 27, pp. 65–81.

Cope, Jason M. (2024). The good practices of practicable alchemy in the stock assessment continuum: Fundamentals and principles of analytical methods to support science-based fisheries management under data and resource limitations. Fisheries Research, 270: 106859.

Cooley, Sarah, and others (2022). Oceans and coastal ecosystems and their services. In Climate change 2022: Impacts, adaptation and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change, H.-O. Pörtner, Hans-0tto, and others, eds. Cambridge University Press, Cambridge, UK and New York, USA, pp. 379–550.

Corso, Andrew D., and others (2024). Thermal tolerance of larval Antarctic cryonotothenioid fishes. Polar Biology, vol. 47, No. 8, pp. 731–740.

Craig, Kevin J., and others (2021). Ecosystem Status Report for the U.S. South Atlantic Region. NOAA Technical Memorandum, NMFS-SEFSC-753, pp. 1–145.

Cruz, Leonardo, and others (2024). Fisheries track the future redistribution of marine species. Nature Climate Change, vol. 14, No. 10, pp. 1093–1100.

Dalpadado, Palmini, and others (2023). Rapid climate change alters the environment and biological production of the Indian Ocean. Science of The Total Environment, vol. 906, art. 167342.

Di Natale, Antonio, and others. (2019). Is the bluefin tuna slowly returning to the Black Sea? An updating of our knowledge on bluefin tuna in the eastern Mediterranean Sea. Collected volumes of scientific papers. International commission for the conservation of Atlantic tunas, ICCAT, Madrid, vol. 75, No. 6, pp. 1261–1277.

Di Natale, Antonio (2021). Is the swordfish slowly returning into the Black Sea? Recent evidences. SCRS/2020/092, Collected volumes of scientific papers, International commission for the conservation of Atlantic tunas, ICCAT, Madrid, vol. 78, No. 7, pp. 142–152.

Di Natale, Antonio, and others (2022). Unusual presence of bluefin tuna in the Gulf of Aden and in the Indian Ocean. 8th working party on temperate tunas (WPTMT), 13–15 April 2022, Indian Ocean tuna commission, IOTC, Mahe (Seychelles), IOTC-2022-WPTmT08DP-19, pp. 1–8.

Duan, Mi, and others (2024). The feeding strategies of the antarctic lanternfish *electrona antarctica* (pisces: myctophidae) in the amundsen and cosmonaut seas (southern ocean), assessed with a classification tree analysis. Polar Biology, vol. 47, No. 5, pp. 515–532.

Dulvy, Nicholas K. and others (2021). Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. Current Biology, vol. 31, No. 21, pp. 1–15.

Falcón, Jesús M., and others (2023). Peces marinos tropicales exóticos de Canarias. RedPromar. Ed. Consejería de Transición Ecológica, Lucha contra el Cambio Climático y Planificación Territorial del Gobierno de Canaria, pp. 1–249.

FAO (2020). https://www.fao.org/in-action/eaf-nansen/news-events/detail/fr/c/1269478/.

FAO (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome.

Fernández-Castro and others (2022). Intense upper ocean mixing due to large aggregations of spawning fish. Nat. Geosci. 15, 287–292.

Froese, Rainier, and Daniel Pauly, eds. (2000). FishBase 2000: concepts, design and data sources. ICLARM, Los Baños, Laguna, Philippines. pp. 344.

Galanidi, Marika, and others (2023). Validated inventories of non-indigenous species (NIS) for the Mediterranean Sea as tools for regional policy and patterns of NIS spread. Diversity, vol. 15, pp. 962.

GBIF (2024). Global Biodiversity Information Facility. www.gbif.org.

Gerringer, Mackenzie. E., and others (2017). *Pseudoliparis swirei* sp. nov.: A newly-discovered hadal snailfish (Scorpaeniformes: Liparidae) from the Mariana Trench. Zootaxa, vol. 4358, No. 1, pp. 161–177.

GFCM FAO (2024). Sub-regional group on stock assessment for the Black Sea (SGSABS). Black Sea Explore data.

Gissi, E., and others (2021). A review of the combined effects of climate change and other local human stressors on the marine environment. Science of Total Environment, vol. 755, art. 142564.

Goethel, Daniel R., and others (2023). Spatial awareness: good practices and pragmatic recommendations for developing spatially structured stock assessments. Fisheries Research, vol. 264, art. 106703.

Gordó-Vilaseca, Cesc, and others (2023). Three decades of increasing fish biodiversity across the northeast Atlantic and the Arctic Ocean. Proceedings of the National Academy of Sciences. vol. 120, No 4, art. e2120869120.

Gordó-Vilaseca, Cesc, and others (2024). Future trends of marine fish biomass distributions from the North Sea to the Barents Sea. Nature communications, vol. 15(1), No. 14, art. 5637.

Gramcianinov, Carolina B., and others (2023). Recent changes in extreme wave events in the south-western South Atlantic. In 7th edition of the Copernicus Ocean State Report (OSR7), Von Schuckmann, K., and others, eds. Copernicus Publications, State Planet, 1-osr7, 12.

Greco, S., Gaetano, A.S., eds. (2022). Gene expression profiling of *Trematomus bernacchii* in response to thermal and stabling stress. Fishes, vol. 7, No. 6, art. 20.

Hastings, Reuben A, and others (2020). Climate change drives poleward increases and equatorward declines in marine species. Current Biology, vol. 30, No. 8, pp. 1572–1577.

Hidalgo, Manuel, and others, eds. (2024). Transboundary population structure of sardine, European hake and blackspot seabream in the Alboran Sea and adjacent waters – A multidisciplinary approach. Studies and Reviews, No. 104 (General Fisheries Commission for the Mediterranean). Rome, FAO.

Hidalgo, Manuel, and others (2018). Climate change impacts, vulnerabilities and adaptations: Mediterranean Sea and the Black Sea marine fisheries. Impacts of climate change on fisheries and aquaculture, 139.

Howell, Daniel, and others (2024). Report series: IMR-PINRO 2024-7 Published: 21.06.2024 Updated: 14.08. 2024.

ICES (2021). Second workshop on Atlantic chub mackerel (*Scomber colias*) (WKCOLIAS2). ICES Scientific Reports. vol. 3, No. 18, pp. 1–231.

ICES. (2022). Greater North Sea ecoregion – fisheries overview. ICES Advice: Fisheries Overviews. Report.

ICES (2024). Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK). ICES Scientific Reports. vol. 6, No. 38, pp. 1249.

International Union for Conservation of Nature (IUCN) (2024). All species IUCN categories. The IUCN red list of threatened species 2024. https://www.iucnredlist.org. Accessed on 26 August 2024.

Jacox, Michael G., and others (2020). Thermal displacement by marine heatwaves. Nature, vol. 584, pp. 82–86.

Kang, Myounghee, and others (2024). Acoustic characterization of fish and macroplankton communities in the Seychelles-Chagos thermocline ridge of the southwest Indian ocean. Deep Sea Research Part II: Topical Studies in Oceanography, vol. 213, art. 105356.

Kleiber, D., and others (2015). Gender and small-scale fisheries: a case for counting women and beyond. Fish and Fisheries. vol. 16, No. 4, pp. 547–562.

Lehodey, Patrick, and Senina Inna (2018). Pacific tuna & climate: Trends and forecasts. Infofish International, vol. 3, pp. 44–47.

Leonetti, Francesco L., and others (2024). Studying chondrichthyans using baited remote underwater video systems: A review. Animals, vol. 14, No. 13, art. 1875.

Marsac, Francis, and others (2024). Indian Ocean primary productivity and fisheries variability. In the Indian Ocean and its role in the global climate system. Elsevier, pp. 245–264.

Lian, Peng, Gao, Le (2024). Impacts of central-Pacific El Niño and physical drivers on eastern Pacific bigeye tuna. Journal of Oceanology and Limnology, vol. 42, pp. 972–987.

Looby A., and others (2022). A quantitative inventory of global soniferous fish diversity. Reviews in Fish Biology and Fisheries, vol. 32, pp. 581–595.

Manel, S., Guerin, PE., Mouillot, D. and others (2020). Global determinants of freshwater and marine fish genetic diversity. Nature Communications, vol. 11, art. 692.

Mateos-Molina, D. and others (2024). Coastal lagoons in the United Arab Emirates serve as critical habitats for globally threatened marine megafauna. Marine Pollution Bulletin, vol. 200, art. 116117.

Matley, J., and others (2024). Long-term effects of tagging fishes with electronic tracking devices. Fish and Fisheries, vol. 25, pp. 1009–1025.

Miller E.C., and others (2018). Explaining the ocean's richest biodiversity hotspot and global patterns of fish diversity. Proceedings of The Royal Society B, vol. 285, art. 20181314.

Minicheva, G., and others (2023). Reaction of the marine ecosystem to the consequences of destruction of the Kakhovka Reservoir dam. Marine Ecological Journal. Nos. 1–2, pp. 52–68.

Moore, B. R., and others (2020), Defining the stock structures of commercial tunas in the Pacific Ocean II: sampling considerations and future directions. Fisheries Research. vol. 230, art. 105524.

Moltó, Vicenç, and others (2024). Predicting fish spawning phenology for adaptive management: Integrating thermal drivers and fishery constraints. Marine Environmental Research, vol. 202, art. 106713.

Muñoz-Pérez, J.P., and others (2023). Galápagos and the plastic problem. Frontiers in Sustainability, vol. 4, art. 1091516.

Nagelkerken, Ivan, and others (2023). The effects of climate change on the ecology of fishes. PLOS Climate, vol. 2, No. 8, art. e0000258.

Nilsen, Ina, and others (2022). Exploring the role of Northeast Atlantic cod in the Barents Sea food web using a multi-model approach. Fish and Fisheries, vol. 23, No. 5, pp. 1083–1098.

Notarbartolo, di Sciara G. (2021). Towards an “Important Shark and Ray Area” (ISRA) process: implementation strategy. Report to IUN Species Survival Commission Shark Specialist Group, pp. 42.

Novillo, Manuel, and others (2024). First insights into the influence of temperature on reproduction in Antarctic fish: The case of *Notothenia coriiceps*. Estuarine Coastal and Shelf Science, vol. 297, pp. 12.

Oliver, Eric, and others (2021). Marine Heatwaves. Annual Review of Marine Science. vol. 13, pp. 313–342.

Ogorelec, Ziga, and others (2022). Can young-of-the-year invasive fish keep up with young-of-the-year native fish? A comparison of feeding rates between invasive sticklebacks and whitefish. Ecology and Evolution, vol. 12, No. 1.

O'Hara, Casey C., and others (2021). At-risk marine biodiversity faces extensive, expanding, and intensifying human impacts. Science, vol. 372, No. 6537, pp. 84–87.

Orozco-Ruiz, A. M., and others (2023). Genetic analyses reveal a non-panmictic genetic structure in the sablefish *Anoplopoma fimbria* in the northern Pacific. ICES Journal of Marine Science, vol. 80, No. 5, pp. 1319–1328.

Öztürk, Bayram (2021). Non-indigenous species in the Mediterranean and the Black Sea. Studies and Reviews, General Fisheries Commission for the Mediterranean. Rome, FAO, No. 87.

Paolo, Fernado S., and others (2024). Satellite mapping reveals extensive industrial activity at sea. Nature, vol. 625, pp. 85–91.

Peña, M. (2024). Atlantic versus Mediterranean deep scattering layers around the Iberian península. Progress in Oceanography, 221: 103211.

Perez, Jose Aangel Alvarez, and Sant’Ana, Rodrigo (2022). Tropicalization of demersal megafauna in the western South Atlantic since 2013. Communications Earth and Environment, vol. 3, art. 227.

Pinheiro, H.T., Shepherd, B., Castillo, C. and others (2019). Deep reef fishes in the world’s epicenter of marine biodiversity. Coral Reefs, vol. 38, pp. 985–995.

Phillips, Genevieve, A. C., Ogier, Eily, and others (2025). The ambiguous role of partially protected marine protected areas in Australia: Results from a systematic literature review. PLOS one, vol. 20, No. 1, art. e0307324.

Pita, P., and others (2023). Mind the gender gap in marine recreational fisheries. Sustainability, vol. 15, No. 14, art. 11292.

Racault, M.F., Rost, B., and Skern-Mauritzen, M. (2022). Oceans and Coastal Ecosystems and Their Services. In Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf,

S. Löschke, V. Möller, A. Okem, B. Rama, eds., Cambridge University Press, Cambridge, UK and New York, USA, pp. 379–550.

Queiroz, N., and others (2021a). Reply to: Caution over use of ecological big-data for conservation. Nature, vol. 595, pp. E20–E28.

Queiroz, N., and others (2021b). Reply to: Shark mortality cannot be assessed by fishery overlap alone. Nature, vol. 595, pp. E8–E16.

Queiroz, N., and others (2019). Global spatial risk assessment of sharks under the footprint of fisheries. Nature, vol. 572, pp. 461–466.

Receveur, A., and others (2024). Long-term changes in taxonomic and functional composition of European marine fish communities. Ecography, vol. 2024, No. 9, art. e07234.

Rice, E.D., and others (2024). The future of gender research in small-scale fisheries: Priorities and pathways for advancing gender equity. Fish and Fisheries, vol. 25, No. 3, pp. 401–408.

Reimer, J.D., and others (2024). The Fourth Global Coral Bleaching Event: Where do we go from here? Coral Reefs, vol. 43, pp. 1121–1125.

Renshaw, S, and others (2023). Global tracking of shark movements, behaviour and ecology: A review of the renaissance years of satellite tagging studies, 2010–2020, Journal of Experimental Marine Biology and Ecology, vol. 560, art. 151841.

Rodriguez-Burgos A.M., and others (2022). The impact of climate change on the distribution of *Sphyrna lewini* in the tropical eastern Pacific. Marine Environmental Research, vol. 180, art. 105696.

Santos BS, and others (2022). The diverse benefits of biodiversity conservation in global ocean areas beyond national jurisdiction. Front. Marine Science, vol. 9, art. 1001240.

Sanz-Martín, Marina, and others (2024). "Climate velocity drives unexpected southward patterns of species shifts in the Western Mediterranean Sea." *Ecological Indicators,* vol. 160, p. 111741.

Savoca M.S., and others (2021). Plastic ingestion by marine fish is widespread and increasing. Global Change Biology, vol. 27, No. 10, pp. 2188–2199.

Sbragaglia, Valerio, and others (2020). Local ecological knowledge of recreational fishers reveals different meridionalization dynamics of two Mediterranean subregions. Marine Ecology Progress Series, vol. 634, pp. 147–157.

Scientific, Technical and Economic Committee for Fisheries (STECF) (2017). Stock assessments in the Black Sea (STECF-17-14). Luxemburg: Publications Office of the European Union, pp. 498.

Smale, D.A., and others. (2019). Marine heatwaves threaten global biodiversity and the provision of ecosystem services. Nature Climate Change, vol. 9, pp. 306–312.

Steiner, N. S., and others (2021). Climate change impacts on sea-ice ecosystems and associated ecosystem services. Elementa-Science of the Anthropocene, vol. 9(1), No. 55, art. 1.

Swaminathan, S.D. and others, (2024). Stony coral tissue loss disease indirectly alters reef communities. Science Advances, vol. 10, No. 18.

Tanaka, K.R., and others (2021). North Pacific warming shifts the juvenile range of a marine apex predator. Scientific Reports, vol. 11, art. 3373.

Tekman, M.B., and others (2022). Impacts of plastic pollution in the oceans on marine species, biodiversity and ecosystems, pp. 1–221, WWF Germany, Berlin.

Tittensor, D., and others (2010). Global patterns and predictors of marine biodiversity across taxa. Nature, vol. 466, pp. 1098–1101.

Vitale, F., L. Worsøe Clausen and G. Ní Chonchúir, eds. (2019). Handbook of fish age estimation protocols and validation methods. ICES Cooperative Research Report, No. 346, pp. 59–102.

Townhill, B. L., and others (2021). Climate change impacts on Atlantic oceanic island tuna. Fisheries Frontiers in Marine Science, vol. 8, art. 634280.

Valastro M., and others (2024). The swordfish CPUE poses several questions and enigmas. A discussion paper. Collect. Vol. Sci. Pap. ICCAT, SCRS/2024/045, vol. 81, No. 3, pp. 1–5.

Vaux F, and others (2021). Adaptive markers distinguish North and South Pacific Albacore amid low population differentiation. Evolutionary Applications, vol. 14, No. 5, pp. 1343–1364.

Wilson, R.J., and others (2021). Large projected reductions in marine fish biomass for Kenya and Tanzania in the absence of climate mitigation. Ocean & coastal management, vol. 215, art. 105921.

Vyshnevskyi V., and others (2023). The destruction of the Kakhovka dam and its consequences, Water International, vol. 48, No. 5, pp. 631–647.

Yapıcı, S. (2021). A Risk Screening of Potential Invasiveness of Alien and Neonative Marine Fishes in the Mediterranean Sea: Implications for Sustainable Management. Sustainability, vol. 13, art. su132413765.

Wang, J. (2025). The BBNJ Agreement: Achievements and Prospects. Chinese Journal of Environmental Law, 9(1), 88–106.

Womersley, F. C., and others (2024). Identifying priority sites for whale shark ship collision management globally. The Science of the Total Environment, 934.

Wootton, N., and others (2021). Microplastic in fish – A global synthesis. Reviews in Fish Biology and Fisheries, vol. 31, pp. 753–771.

Worm, B., and others (2024). Global shark fishing mortality still rising despite widespread regulatory change. Science, vol. 383, No. 6679, pp. 225-230.

Zarco-Perello, S., and others (2022). Maximization of fitness by phenological and phenotypic plasticity in range expanding rabbitfishes (Siganidae). Journal of Animal Ecology, vol. 91, No. 8, pp. 1666–1678.

Zenetos, A., Galanidi, M. (2020). Mediterranean non indigenous species at the start of the 2020s: recent changes. Marine Biodiversity Records, vol. 13, No. 10.