Worldwide review of bottom fisheries in the high seas in 2016

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This technical paper has been prepared under the auspices of the FAO-managed deep-sea bottom fisheries component of the Areas Beyond National Jurisdiction project funded by the Global Environment Facility.

This review is an extended update to the FAO *Worldwide review of bottom fisheries in the high seas* that was published in 2009, based on data originating for the 2003–2006 period.[1] A plan of work was agreed following preparatory discussions at FAO headquarters in Rome in October 2015, and a consultant hired to complete an initial draft with information from fisheries up to and including 2014. This was presented to invited experts from regional Fisheries Management Organizations (RFMOs) in May 2016; they provided valuable suggestions that enabled further development of the document and a revised draft was submitted to FAO in early 2017.[2]

FAO hired a second consultant to consolidate the text, tables and figures, and update the focus year to 2016. This was circulated to RFMOs for comment in 2018, with a publication-ready version available in the middle of 2019. A summary was presented to the *ABNJ Deep sea meeting* held at FAO headquarters, Rome, on 7–9 May 2019 by Anthony Thompson.[3]

1 Bensch, A., Gianni, M., Gréboval, D., Sanders, J.S. & Hjort, A. 2009. *Worldwide review of bottom fisheries in the high seas*. FAO Fisheries and Aquaculture Technical Paper No. 522 (Rev.1.). Rome, FAO. 145 pp. (also available at http://www.fao.org/3/i1116e/i1116e00.htm).

2 ABNJ Deep Seas Project. 2016. *Record of the workshop of regional deep sea fisheries management bodies in support of the Worldwide Review of Bottom Fisheries in the High Seas. 3–5 May 2016*. Rome, FAO. ABNJ Deep Seas Project Sustainable Fisheries Management and Biodiversity Conservation of Deep-sea Living Marine Resources and Ecosystems in the Areas Beyond National Jurisdiction Project Report, ABNJ_DSP-2016-Doc-02. 12 pp. (also available at http://www.fao.org/3/a-i6341e.pdf)

3 ABNJ Deep Seas Project. 2019. *Sustainable Fisheries Management and Biodiversity Conservation of Deep-sea Living Marine Resources and Ecosystems in the Areas Beyond National Jurisdiction, 7–9 May 2019*. Rome, FAO. 74 pp.

Abstract

The *Worldwide review of bottom fisheries in the high seas in 2016* is an extended update to the *Worldwide review of bottom fisheries in the high seas* that was published in 2009 based on information from 2003–2006. It provides states and other interested parties with a summary of the current status of high seas bottom fisheries worldwide. The current review follows the same format as before, centred around regional chapters covering the major Ocean areas beyond national jurisdiction (ABNJ or high seas). However, in this edition additional summary chapters precede the regional descriptions, dealing with ecosystems and resources, bottom fisheries, and management. Furthermore, this review provides much greater detail on the history and development of the high seas bottom fisheries, which provides background information that is essential to understanding the current state of these fisheries. The focus year is 2016, ten years on from the first review.

This review focuses on the high seas bottom fisheries that contribute approximately 0.3 percent to the global marine capture fisheries production. The updated global high seas catch from bottom fisheries was estimated at 226 000 tonnes in 2016, which is similar to the 250 000 tonnes previously estimated for 2006. There have been numerous improvements to catch estimation over the last decade, and estimates are now more reliable. Since 2003 four new RFMOs that monitor and manage bottom fisheries have been established in the southeast Atlantic, north Pacific, south Pacific, and Indian Ocean. However, most bottom catches remain with the more established RFMOs in the northwest Atlantic, northeast Atlantic, Mediterranean and Southern Ocean.

There have not been any marked changes in the state of high seas fish stocks over the past ten years, both in terms of the quantity landed and species composition between shellfish and finfish species. A survey of 49 demersal fish stocks in 2014–2016 showed that 25 percent were fished sustainably, 26 percent were in an intermediate status, and 6 percent were overfished or at low levels. The status of the remaining 42 percent of the fished stocks was unknown.

This review does highlight the considerable changes that have occurred in the monitoring and management of the high seas deep-sea fisheries by RFMOs, including the regulation relating to total allowable catches and reducing impacts on both target and bycatch species. Owing to space requirements, only the briefest of summaries on the implementation, monitoring and enforcement of these regulations is provided in this review, usually based on RFMO compliance reports and performance reviews. Interested readers can seek further information on the RFMO websites.

The difficulties in acquiring consistent data at the global level have meant that the present review rather skims over non-commercial bycatch and vulnerable species. There is a significant amount of regionally specific information on the RFMO websites and contained in their reports – and interested readers are urged to consult these for further details, and indeed to update the information provided in this review. A good summary of the impacts to benthic habitats is provided the FAO publication on vulnerable marine ecosystems[4], and its associated database[5].

[4] Thompson, A.B., Sanders, J., Tandstad, M., Carocci, F. & Fuller, J., eds. 2016. *Vulnerable marine ecosystems: processes and practices in the high seas*. FAO Fisheries and Aquaculture Technical Paper No. 595. Rome, FAO. 172 pp. (also available at http://www.fao.org/3/a-i5952e.pdf).

[5] http://www.fao.org/in-action/vulnerable-marine-ecosystems/vme-database/en/vme.html

Acknowledgements

This review is the outcome of many inputs from FAO, regional fisheries bodies managing deep-sea fisheries and the associated fisheries research centres.

The initial drafts, including the methodology for identifying bottom fisheries that are active in the high seas, were prepared by Dr. Trevor Kenchington, while the review was finalized by Anthony Thompson. Both these consultants were helped at every stage by numerous researchers and managers. Special thanks are due to: Tom Blasdale, Mark Belchier, Odd Axel Bergstad, Aurora Nastasi and Aleksandr Zavolokin, who provided invaluable comments and assistance throughout the preparation of this review, and especially during the workshop held at FAO in Rome in May 2016. We also acknowledge the support of staff in the regional secretariats (CCAMLR, CECAF, GFCM, NAFO, NEAFC, NPFC, SEAFO, SPRFMO, WECAFC) who willingly gave their time and expertise to provide information and help improve the drafts through to completion. Also special thanks to Merete Tandstad, William Emerson, Chris O'Brien and Jessica Fuller for their support.

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Acronyms and abbreviations

ABNJ	Area Beyond National Jurisdiction
BPA	Benthic Protection Area
CA	Convention Area (where GFCM is concerned: Competence Area)
CBD	Convention on Biological Diversity
CAMLR Convention	Convention on the Conservation of Antarctic Marine Living Resources
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources (CAMLR Commission)
CECAF	Fishery Committee for the Eastern Central Atlantic
CIESM	Commission Internationale pour l'Exploration Scientifique de la Méditerranée
CM	Conservation Measure (CCAMLR & SEAFO term)
CEM	Conservation and Enforcement Measure (NAFO term)
CMM	Conservation and Management Measure (SPRFMO & SIOFA term)
COFI	FAO Committee on Fisheries
DG MARE	European Union, Directorate-General for Maritime Affairs and Fisheries
EAF	Ecosystem approach to fisheries
EEZ	Exclusive Economic Zone
EU	European Union – in historical accounts, also used for the European Economic Community (1958–67) and the European Communities (1967–93)
FAO	Food and Agriculture Organization of the United Nations
GFCM	General Fisheries Commission for the Mediterranean
GPS	Global Positioning System
GSA	Geographical Sub-Area (GFCM term)
ICES	International Council for the Exploration of the Sea
IUU fishing	Illegal, Unreported and Unregulated fishing
LIW	Levantine Intermediate Water
MAP	Mediterranean Action Plan
MPA	Marine Protected Area
NAO	North Atlantic Oscillation
NAFO	Northwest Atlantic Fisheries Organization
NEAFC	North East Atlantic Fisheries Commission
NPFC	North Pacific Fisheries Commission
PECMAS	Permanent Committee on Management and Science (of NEAFC)

RA	Regulatory Area
RFMO/A	Regional Fisheries Management Organization or Arrangement
SAC	Scientific Advisory Committee (of GFCM)
SEAFO	South East Atlantic Fisheries Organization
SIODA	Southern Indian Ocean Deepsea Fishers Association
SIOFA	Southern Indian Ocean Fisheries Agreement
SPRFMO	South Pacific Regional Fisheries Management Organization
STACFEN	Standing Committee on Fisheries Environment (of NAFO)
TAC	Total Allowable Catch
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNGA	United Nations General Assembly
US	United States of America (possessive form of name)
USA	United States of America (see "US")
USSR	Union of Soviet Socialist Republics
VME	Vulnerable Marine Ecosystem
VMS	Vessel Monitoring System
WECAFC	Western Central Atlantic Fishery Commission
WGSAD	Working Group on Stock Assessment of Demersal Species (of GFCM's SAC)

Executive summary

The *Worldwide review of bottom fisheries in the high seas in 2016*, like its processor published in 2009 (based on information from 2003–2006), provides states and other interested parties with a summary of the current status of high seas bottom fisheries worldwide.

In summary, the updated global high seas catch from bottom fisheries was estimated at 226 000 tonnes in 2016, comprising of bony fish (teleosts, 72 percent), shrimps (15 percent), squid (7 percent), cartilaginous fish (elasmobranchs, 3 percent) and crabs (3 percent). This is similar to the 250 000 tonnes previously estimated for 2006. There have been many improvements in catch estimation over the last decade, and estimates are now more reliable.

This current review provides an updated analysis of finfish and shellfish caught in the high seas by fishing gears that normally come into contact with the seafloor during normal operations. In some regions, demersal species are also harvested using deep pelagic trawls that do not normally come into contact with the seafloor; where appropriate, these have been included in this review when they clearly catch demersal species associated with the sea floor.

The use of "high seas" in this review follows UNCLOS, being waters *above* the seabed and not included in exclusive economic zones, territorial waters, or internal waters. Strictly speaking, the term "Areas Beyond National Jurisdiction" includes the high seas and seabed beyond national jurisdiction, although the terms are often used interchangeably within a fisheries context. The extended continental shelf is that portion of the seabed that lies beyond the EEZ to a limit of 350 nautical miles, and if claimed and recognised, is under national jurisdiction. In some cases, the EEZ and extended Continental shelf have not been claimed or are not internationally recognised, in which case the ABNJ starts from the limits of the State's territorial sea (or contiguous zone). Sedentary species, typically including crabs and molluscs, occurring on the extended continental shelfs lying between 200–350 nautical miles from the coastlines, are included in this review, though their management is governed nationally.

This review provides information on the current high seas fisheries for demersal species caught with gears that contact the seabed during normal use, with a focus on 2016. It does however have an extended scope over the first review and covers the early development of the bottom fisheries from the late 1800s through to the 1960s. It also includes more information on ecosystem productivity and the drivers that control trends and variability. Chapters 1–4 provide the background information at the global level on the high seas ecosystems and benthic fishery resources, and the variety of bottom fisheries exploiting these deep-sea finfish and shellfish resources, including bottom trawls, longlines, pots and gillnets. Deep mid-water trawls are becoming increasingly common and have several advantages over bottom trawls in being more targeted with lower bycatch, and generally fewer impacts on the seabed. Catches with trawls are often not separated by bottom and deep pelagic, and so it can be difficult to identify the extent of the use of these two gears. Data collection has improved over the last ten or more years, and much more is displayed on the public areas of the RFMO websites. However, it is still difficult to access more detailed information, especially in the separation of catches from high seas and national waters. This review has made every attempt to do this. Such information is often collected by RFMOs but may be kept confidential for a variety of reasons.

The management of the high seas bottom fisheries, at the global level, is described in Chapter 4. This has been influenced by the adoption of various United Nations

General Assembly (UNGA) resolutions dealing with bottom fisheries and calling for improvements in the management of the target stocks, as well the impacts to associated or dependent species living in the same ecosystem. Following on from this, the high seas bottom fisheries have also been discussed widely as part of the biodiversity debates occurring within the UNGA, CBD and other organisations. Many of the RFMOs have had measures regulating bottom fisheries since the 1990s and earlier, but measures relating to impacts – particularly those concerning vulnerable marine ecosystems – underwent significant development in the 2000s and 2010s. This stimulated a much closer monitoring of bottom fishing vessels using VMS systems, and an improved understanding of the behaviour of the vessels catching demersal species.

The UNGA resolutions also stimulated or hastened the existence of RFMOs in regions not previously covered. Four new RFMOs have been established since the first review: SEAFO in the southeast Atlantic, NPFC in the north Pacific, SPRFMO in the south Pacific, and SEAFO in the Indian Ocean. These newer RFMOs have, in the last few years, adopted management measures to regulate bottom fisheries and the compliance systems to monitor effectiveness. All high seas regions with significant bottom fisheries are now managed by regional management organizations through their member parties, except for the southwest Atlantic where the responsibility remains directly with the flag states of those vessels fishing in international waters.

Regional details of the bottom fisheries throughout the high seas regions of the oceans are covered in Chapters 5–15. These chapters all employ the same format, giving a description of the regions' geographical, ecosystem and resource species, followed by the management regimes and details of historical and current bottom fisheries. Each chapter is designed to be self-contained, with its own text, figures, tables and references. However, it is hoped that the review will serve as a global resource, so that regional information can be understood more fully as part of a wider context.

1. Introduction

The management of bottom fisheries in the high seas and the protection of deep-water ecosystems from the impacts of fishing have been of increasing concern to the international community since the early years of the twenty-first century. They have been discussed at fora ranging from the United Nations General Assembly (UNGA) and high-level meetings organized by the Food and Agriculture Organization of the United Nations (FAO) and the Convention on Biological Diversity (CBD), to conferences and workshops organized by specialized intergovernmental and non-governmental organizations and concerned states. Requests from the 26th and 27th sessions of the FAO Committee on Fisheries (COFI) in 2006 and 2007, together with the adoption of UNGA Resolution 61/105 on Sustainable Fisheries in December 2006, led to the preparation of a *Worldwide review of bottom fisheries in the high seas* which gave special attention to the period 2003–2006 (Bensch *et al.*, 2009). The present review is an update of that earlier publication.

Like its predecessor, this review is intended to provide interested parties with a summary of the current global status of bottom fisheries in the high seas, based on the best information available and embedded within those fisheries' ecological and historical contexts. It is a companion to *Vulnerable marine ecosystems: processes and practices in the high seas* (Thompson *et al*., 2016), which considers the impacts of the fisheries on vulnerable marine ecosystems (VMEs) and the management responses to them that have been adopted by, or under, regional fisheries management organizations or arrangements (RFMO/As) or by flag states.

SCOPE

The term "high seas" is recognized by the United Nations Convention on the Law of the Sea (UNCLOS, 1982) and is that area of the oceans which is not subject to the jurisdiction of any one state. In general, and with the adoption of extended exclusion zones (EEZs) by many states, it lies beyond 200 nautical miles from the coastal baseline. There are many exceptions, but those of the Mediterranean Sea and Antarctic are the most significant where the high seas comes much closer to land masses. National claims on the continental shelf beyond 200 nautical miles are limited to resources occurring on the sea floor.

The distinction between deep-sea and high seas bottom fisheries is somewhat political. With the occasional exception, all high seas bottom fisheries occur in deep water, mostly at 200–1 500 m depth. Such deep-sea fisheries, often deploying the same gear and targeting the same species, also occur beyond the continental shelves in national jurisdictions, and this is partly the reason why it is difficult to get estimates for just high seas catches.

This review aims to provide comprehensive coverage of all commercial fisheries that use gears which, during the normal course of fishing operations, are likely to contact the seafloor in areas of the World Ocean that fall within the high seas. High seas fisheries that target benthic species are considered here so that the extent of fishing activity in international waters may be fully understood. High seas fisheries for straddling stocks are likewise addressed, which necessitates some consideration of the fishing for those resources in areas under national jurisdiction, though the focus remains on activity in the high seas. Indeed, fisheries that are entirely under national jurisdiction are mentioned where necessary, to provide context for an understanding of those operating in adjacent international waters. However, this review emphasis and summaries are confined to high seas fisheries and thereby address the needs of UNGA and of others concerned with the international management of fisheries.

In much of the World Ocean, the high seas are the areas which lie outside the declared EEZs of coastal states. No distinction is drawn here between EEZs and the various other forms of declared fisheries jurisdictions extending 200 nautical miles from coastal baselines, nor are conflicting claims to jurisdiction over some areas considered. The high seas are not, however, simply all areas that lie more than 200 nautical miles from the coast: as a few islands are surrounded only by Territorial Seas, all claims of national jurisdiction off Antarctic coastlines are currently in abeyance, and further issues arise in the Mediterranean Sea. These complications are addressed in the regional chapters which follow.

Fisheries that use fully pelagic gears in the surface to mid-water zones are not considered here. However, deep pelagic trawls that fish close to the seabed and have occasional accidental contact are included, especially where the same resources are also exploited by bottom-contact fishing gears. In the deep ocean, beyond the continental shelves, there is only limited overlap in the depth distributions of pelagic and bottom-associated resource species, making that distinction readily applicable.

The fisheries primarily considered here are broadly equivalent to "Deep-Sea Fisheries", as that term is defined in the FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (hereafter: the FAO Guidelines; FAO, 2009) – meaning those fisheries conducted in areas beyond national jurisdiction (ABNJs), using gears which are likely to come into contact with the seafloor during the normal course of fishing operations, and which take (if only as bycatch) species that can only sustain low exploitation rates. Most bottom fisheries do catch such species, at least occasionally, and the exceptions cannot be known without detailed study. The latter criterion has therefore not been applied in this review.

This orientation is different from those of many other published accounts, some of which have considered fisheries operating below a chosen depth, in both EEZs and the high seas, while others have examined fisheries for species with selected biological characteristics deemed typical of deep-living resources, or else those inhabiting particular environments, such as seamounts or submarine canyons – again without regard to jurisdictional boundaries. In the past there has been a tendency to conflate the bottom fisheries in the high seas, those at great depth, those on seamounts and those targeting long-lived, low-productivity resources. As shown in the chapters which follow, very different groups of fisheries are delimited by each of those criteria. Hence, the picture presented in this review differs from those offered in other works with different orientations.

The principal temporal focus of this review is on 2016, the most recent year for which near-comprehensive catch data are available for the fisheries of interest. However, a significant amount of relevant information is only available in published studies, which necessarily rely on earlier information. As such, the overall summaries presented here are of the fisheries as they were in 2016, but the scope of this review is not confined solely to that date.

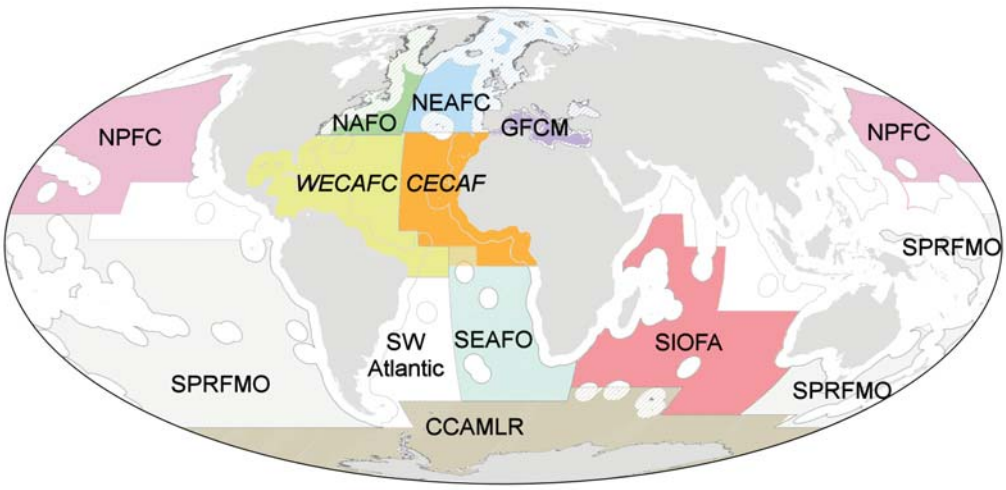
ARRANGEMENT

The three chapters which follow offer a global overview of the world's high seas bottom fisheries, including not only the fisheries themselves and their historical development but also their resources and the ecological foundations of those resources, as well as the systems developed for the management of the fisheries. The overview is designed to be read as a stand-alone review of the fisheries of present interest, by those who do not require detailed information on particular regions.

The remainder of this review comprises chapters on each major region of the World Ocean – the regions being delimited primarily (though not exclusively) by the

Convention or Regulatory Areas, or other areas of application, of those RFMO/As which manage the bottom fisheries in the high seas (Figure 1.1). Each chapter addresses the seabed available for the region's high seas fishing areas; the ecosystems and resources on that seabed, and the regional management system applicable – including its monitoring and enforcement aspects – as well as mechanisms for generating scientific advice. The prime focus, however, is on the fisheries themselves. The FAO Fisheries Glossary defines a "fishery" as "an activity leading to harvesting of fish"; this review adopts a broader view: while the magnitude of the harvesting (usually represented by the quantity of landings) is emphasized, the gears and techniques used, the grounds fished, the commercial and social structures of the fisheries, post-harvest product processing and the markets supplied are all considered – to the extent that accessible information permits. Unfortunately, it rarely permits much understanding of those wider concerns and, for some fisheries, even compiling landings information has proven challenging.

FIGURE 1.1
The World Ocean showing the regions recognized in this review



Solid shading represents areas of the high seas with bottom fisheries managed under multilateral agreements. Grey lines are 200 nautical mile arcs.
Source: FAO VME Database, shading and names added.

Ocean	Management (*advisory*[1]) body	
Northeast Atlantic	NEAFC	North East Atlantic Fisheries Commission
Northwest Atlantic	NAFO	Northwest Atlantic Fisheries Organization
Central Atlantic	*CECAF*[1]	*Fishery Committee for the Eastern Central Atlantic*
	WECAFC[1]	*Western Central Atlantic Fishery Commission*
Southeast Atlantic	SEAFO	South East Atlantic Fisheries Organization
Southwest Atlantic		none
Mediterranean Sea	GFCM	General Fisheries Commission for the Mediterranean
North Pacific	NPFC	North Pacific Fisheries Commission
South Pacific	SPRFMO	South Pacific Regional Fisheries Management Organization;
Indian	SIOFA	Southern Indian Ocean Fisheries Agreement
Southern	CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
Arctic		none

Throughout, the intention is to provide information by individual "fishery". The FAO Fisheries Glossary states that such a unit is typically "defined in terms of some or all of the following: people involved, species or type of fish, area of water or seabed, method of fishing, class of boats and purpose of the activities." The high seas fisheries are generally free of much of the complexity of coastal activities and it is usually possible to recognize discrete fisheries, each defined by target species (often in the plural), major gear type or types, and sometimes intra-regional fishing grounds or flag states – the latter are important where the fleets of coastal states operate transboundary fisheries, spanning both EEZ and high seas. It is, however, unusual for any two fishing trips to be identical and hence no fishery can be homogeneous, while many are not entirely discrete. Hence, the limits drawn around any one fishery must often be partly arbitrary.

METHODOLOGY

This review was built on the work of Bensch *et al*. (2009) but does not repeat their use of a questionnaire approach. Rather, published and publicly available information was compiled, much of it drawn from the relevant RFMO/As, and used to prepare lists of the fisheries of interest. Since the published material necessarily examines the past, albeit the recent past, it proved most effective to trace the developmental histories of the various fisheries. Once the fisheries in each region were listed, available information on the topics covered by the review was sought from wherever it might be available. The sources used are indicated by the citations in the regional chapters, the only exception being that information drawn from the RFMO/As' websites, which is generally not given specific attribution.

A first draft of each chapter was generated and reviewed by a workshop held at FAO in Rome in May 2016, to which scientists from each RFMO/A were invited (FAO, 2016). The review was then reworked and expanded, in line with the workshop's recommendations. The new draft was again reviewed by RFMO/A staff and scientists, before being refined and corrected. All who contributed are named in the Acknowledgements.

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2. The high seas, their ecosystems and fishery resources

THE WORLD OCEAN

The solid surface of our planet comprises continents and ocean seabed. The submerged edges of the continents typically lie some 200 m below the surface to form the continental shelves, which collectively make up nearly 9 percent of the world's seabed (Harris *et al*., 2014). The shelf break on the outer edge of each shelf is usually marked by a steep continental slope. The topography of the slopes is often very rough, often with sharp ridges, gullies and submarine canyons. The continental shelves are generally less than 200 nautical miles wide and hence the continental slopes are mostly subject to national jurisdiction.

There are many exceptions to these generalizations that are relevant to the bottom fisheries of interest to this review. For example, the weight of ice depresses Antarctica, so that its shelf break is several hundred metres below sea level. The continent of Zealandia has a large, unusually deep continental shelf. Some continental slopes are smoother and more gently sloping, such as those off parts of Patagonia. Of special importance to this review, some continental shelves are so wide that they project into the high seas: this is true of the easternmost portion of the Grand Banks of Newfoundland and one area of the Patagonian Shelf to the east of Argentina. Other shelves, such as those along the Eurasian side of the Arctic Ocean and the extensive area of Zealandia, are no less wide but are home to offshore islands surrounded by areas of national jurisdiction which cover most or all those shelves.

The continental slopes plunge to the deep-ocean floor at depths below 4 000 m, mostly composed of abyssal plains and hills. A variety of geomorphological features cause the seabed of the high seas to rise to 2 000 m depth or less; these include isolated fragments of continent, notably the Flemish Cap in the northwest Atlantic and the Rockall Plateau in the northeast Atlantic. The mid-ocean ridges are linear features where new ocean floor is created as tectonic plates move apart. They generally bear seamounts which, in some cases, rise to just under 2 000 m depth. Other seamounts are formed from magma as an oceanic plate moves across a "hotspot" in the mantle; this forms a volcano, which can sometimes grow above the sea surface as an island. As the plate moves, volcanoes) become isolated from their source of magma and decline into extinction, before gradually sinking back into the mantle under their own weight. This creates a seamount chain. Many isolated seamounts have been formed in the same way.

ECOSYSTEM PRODUCTIVITY

Phytoplankton photosynthesis

The energy which passes through marine ecosystems, including the portion which becomes the calorie content of seafood for human consumers, comes from several sources. The overwhelming majority is drawn from sunlight and captured by phytoplankton photosynthesis. As well as light, aquatic algae requires inorganic nutrients (primarily nitrate, phosphate and silicate). Sufficient light for photosynthesis to exceed respiration, required for growth, is limited to some tens of metres beneath the sea's surface. Indeed, much of the net production happens in the uppermost few metres.

The supply of nutrients for large-scale phytoplankton production mostly depends on the upwelling of deeper water to the surface. There are many mechanisms of local importance to fisheries but, at the global scale, the dominant process involves the eastern boundary currents of the main ocean basins: the Humboldt, Benguela, California and Canary currents, which flow towards equatorial latitudes. The Indian Ocean is an exception as its eastern boundary current, the Leeuwin Current, flows poleward and is not associated with major upwelling. By virtue of the Earth's rotation and its effects, the winds blowing over those currents tend to drive the water offshore, generating upwelling and major production of both phytoplankton and fishery resources. That production has played an important role in the development of deep-sea fisheries. However, the continental shelves on the eastern sides of the four major basins do not extend far beyond the outermost islands; the ecosystems associated with the four currents therefore lie largely, or completely, within areas now under national jurisdiction. Hence, few high seas fisheries are supported by these systems directly.

Downward transport of energy

Since almost all primary production occurs in the uppermost tens of metres of the water column, the deeper water benthic fishery resources (and the fisheries which depend on them) rely on the downward transport of organic material and the energy it contains. That material serves either as food for the resource species themselves or their prey. The downward flux is rapid in the uppermost 200 m or so. Where the seabed is shallow enough – mostly on the continental shelves – much of that flux is captured by benthic ecosystems by way of a process that is still poorly understood, termed "benthic-pelagic coupling", which supports the prey of demersal fish.

Two principal mechanisms carry the downward flux of organic material and energy below 200 m depth in open ocean. The majority of what reaches the deep-ocean floor does so through the passive sinking of small, non-living particles; however, this accounts for less than 10 percent of primary production, as most is recycled in the upper 200 m. The second mechanism is active animal vertical migration. In most of the waters of the temperate and high latitudes where rich phytoplankton blooms occur, the principal herbivores are calanoid copepods. During the bloom periods they feed close to the surface at night and swim down tens of metres at dawn. However, following their feeding and spawning seasons, most species overwinter at depths of hundreds of metres. Euphausiid krill are herbivores and predominate in the Southern Ocean; they also overwinter at depth, but have diel migrations during the feeding season that carry them down to depths of a few hundred metres. A third group that plays an important role in the downward flux is the myctophid lanternfish. They also feed near the surface at night on copepods, krill, and even small fish, but migrate down to depths of several hundred metres at dawn. In short, there can be a ready supply of suitable prey for larger predatory fish at subsurface depths down to 500–1 000 m.

Additional mechanisms operate along the continental margins. These can provide very substantial exports of organic-rich sediment, flowing from the continental shelves down the slopes, especially through submarine canyons. The organic fraction is recycled through the benthos and packaged into suitable prey for fish or shellfish suitable for human consumption, but it may nevertheless enhance resource production. This process is especially significant in parts of the Mediterranean Sea but it may have a larger effect on fisheries elsewhere which has yet to be recognized. There can also be active seasonal migration of continental-shelf resources into deeper water for the winter, such as the first bottom-trawl fishery in the modern high seas exploiting the Atlantic cod of Grand Bank at depths down to 400 m in the spring.

Seamounts and other isolated features set amidst the deep ocean are generally less productive than continental slopes of the same depth, because they lack the supply of material and energy from adjacent shelves. Seamounts may, however, trap some of the production from large upstream areas as organic material is carried past on the current.

Resource productivity

Much has been made of the supposedly long lives, slow growth, late maturation, low fecundity and irregular recruitment of deep-living resource species. All of these are indicators of the "slow growth rate" population dynamics that lead to real management challenges.

Their relationship to the depths of various fisheries is less sure. Morato *et al.* (2006) offer a graph of the maximum ages of resource species against depth, in which the mean maximum age at each depth was weighted by the global catches of the various species in 2001. Their representation suggests that the mean maximum age passes 100 years at a depth of about 1 100 m and approaches 150 years at 1 300 m. However, the graph offers a distorted impression: while the weighted means may generally increase with depth, there are both short- and long-lived species, including resource species, at all depths (cf. Large *et al*., 2003). High seas catches at upper-slope depths have been dominated by Sebastinid redfishes, but globally Merluccid hakes have been predominant in that zone. The latter have annual natural mortality rates of about 0.2 or often rather higher. Sebastinids, by contrast, include very long-lived species. The greatest age yet reported for any teleost was 205 years for a rougheye rockfish – once an important resource species in the North Pacific and most abundant at depths of 150–450 m (Love *et al*., 2002). Pelagic armourhead, taken at similar depths on North Pacific seamounts, have a maximum age of only about 10 years and an annual natural mortality rate of perhaps 0.5 (Kiyota *et al*., 2016).

At mid-slope depths, orange roughy reach 150 years (Andrews *et al*., 2009). However, the only resources which have supported large catches from depths of 1 500 m or more – roundnose grenadier, Greenland halibut and the tooth fishes – have much shorter lives. The maximum age of roundnose grenadier, in the absence of fishing, has been variously reported as up to 60 years (Kelly *et al*., 1997; Clarke *et al*., 2003; Norse *et al*., 2012) and the annual natural mortality rate in the northeast Atlantic has been estimated at about 0.1 (Lorance *et al*., 2001; Clarke *et al*., 2003). Patagonian toothfish have a similar life expectancy. Individual ages up to 54 years have been reported (Collins *et al*., 2010), but none greater. There is no validated method for the routine ageing of Greenland halibut and counts of otolith annuli are known to underestimate true ages. However, the maximum confirmed age observed in a small sample from a lightly exploited Arctic population was under 30 years (Treble *et al*., 2008), while the annual natural mortality rate in a Bering Sea population has been estimated by an age-independent method at around 0.1 (Cooper *et al*., 2007).

It remains true that the principal demersal resource species of the continental shelves reach maximum ages of around 30 years, with annual natural mortality rates of approximately 0.2, whereas species fished more than 1 000 m deeper live twice as long and have annual mortality rates nearer 0.1. That may not simply be deep-living species adapting to the limited supply of energy. Rather, the high costs of deep fishing far from ports of landing puts the emphasis on high-value, abundant species, where value often means species with energy-rich, firm flesh, yielding fillets or steaks with a texture that appeals to the high-end, "white-tablecloth" restaurant market – orange roughy and the toothfishes are prime examples. One way for a resource to generate a large biomass of such flesh in an energy-scarce environment is to accumulate annual production over the decades of a high life expectancy. Thus, the longer lives of deeper-living resources may in part be the product of human choices as to which species to target.

In summary, low mortality rates, low turnover rates, high life expectancy and their other correlates pose major challenges for fisheries management. However, although those rates are evident in some of the species of concern to this review, they are not characteristic of deep-living resources, and even less so in resources exploited by bottom fisheries in the high seas.

FISHING AND FISHING GROUNDS

The World Ocean covers nearly 364 000 000 km², of which 61 percent (223 000 000 km²) are high seas outside of the Mediterranean. Only 0.15 percent (336 000 km²) of the latter are shallower than 200 m and only 0.58 percent (1 290 000 km²) shallower than 400 m. Yet that 0.58 percent yields the great majority of the high seas bottom catch, which comes from a considerably smaller area than such simple calculations imply. Low-latitude high seas, most of those in the Arctic Ocean and many temperate seamounts or other isolated features have no viable resources, while commercially viable fishing is only possible in selected parts of even productive fishing areas where valuable resources aggregate. Only 3.1 percent (6 880 000 km²) of the high seas seabed outside the Mediterranean lies above 2 000 m depth and is thus potentially fishable by depth criterion alone; most of the seabed is deeper than 1 000 m, has few if any viable resources, and the generally steep and broken continental slopes, flanks of seamounts and similar seabeds can pose severe challenges to practical fishing. For example, trawlers working the Flemish Pass for Greenland halibut are able to make long tows at great depth, but trawling for orange roughy or longlining for Atlantic halibut can take place only on isolated spots of suitable bottom.[1] In essence, only a very small fraction of the high seas seabed has ever been, or ever will be, fished by bottom-fishing gears.

The basaltic volcanoes that form seamounts tend to form conical peaks that pose great challenges to fishermen. However, the growth of reefs around a subsiding volcanic island, forming an atoll surrounding a shallow lagoon, creates a flat-topped structure. When the rate of subsidence exceeds the upward growth of the reef, the result is a seamount with a flat peak, known as a “guyot” or “tablemount”. The peak can sometimes stretch to tens of kilometres wide, and be comparatively straightforward to fish. While each of the various forms of seamount can be important to fisheries, few high seas examples have been. Most chains and clusters that include seamounts which have peaks at a fishable depth also include other seamounts nearby, which rise above the surface as islands or at least as atolls. These land areas are generally surrounded by broad areas under national jurisdiction; high seas seamount fishing is thus only possible where peaks approach the sea’s surface more than 200 nautical miles from the nearest one which breaks that surface.

Hence, most of the global fishery catch is either taken in the near-surface and shallow midwater “epipelagic” zone, or else by bottom fishing on continental shelves. The epipelagic fisheries (for tuna, mackerel, herring and others) are beyond the scope of this review, but the largest bottom fisheries in the high seas are conducted on those areas of continental shelf which project beyond the limits of national jurisdiction. The largest bottom fisheries of all are located on shelf areas in the EEZs of coastal states.

Outside the Mediterranean, all fishing grounds in the high seas are far from any port of landing. In a few cases, such as the Nova Scotian fishery for Atlantic halibut, as well as in the Mediterranean, it is possible to work such grounds with boats of less than 25 m long, but high seas bottom fisheries typically require large, expensive vessels. Deep fishing further increases operating costs, because a higher proportion of each day is spent in setting and hauling gear, and often requires extensive, costly expeditions to explore and identify new grounds and resources. High seas bottom fisheries thus necessitate valuable demersal resources, usually fish with firm flesh that implies a high protein – and thus very high energy – content. By contrast, many deep-living species

[1] Bottom trawling for orange roughy on high seas seamounts often involves a search for rare, small patches of relatively smooth, relatively level seabed on which the gear can be set. Deep longlining for halibut requires the bait to lie on the bottom where fish will be attracted to them.

adapt to the restricted food supply by having weak flesh. Such resources are only available beneath areas with high phytoplankton production and where the seabed is shallow enough for active animal migration to carry prey downwards to the bottom.

It is therefore no surprise that the principal high seas bottom-fishing grounds are found where continental shelves and upper continental slopes extend beyond the boundaries of national jurisdictions, in temperate and higher latitudes – primarily parts of the Grand Banks and the Patagonian Shelf, but also high seas enclaves in the Barents and Bering seas and the Sea of Okhotsk. Additional grounds include seamounts, ridges and other bathymetric features at similar latitudes, in addition to the continental margin of Antarctica. Elsewhere, some seamounts in warm–temperate areas have seen minor fisheries for alfonsino, while the southern Emperor and northwestern Hawaiian seamounts support a unique resource of pelagic armourhead.

Those various grounds extend from shallow water (a few tens of metres, on the Southeast Shoal of Grand Bank) to depths of over 1 000 m, though the bulk of the catch is taken above approximately 400 m. Only three resources of four species have ever supported much fishing below 1 000 m or any below 1 500 m: roundnose grenadier across the North Atlantic, Greenland halibut in Flemish Pass, and the Patagonian and Antarctic toothfishes around the Southern Ocean and on the continental slopes of South America. Even those are primarily fished above about 1 700 m, though some commercial fishing effort has extended as deep as 2 000 m (Atkinson, 1995; Bowering and Brodie, 1995; Collins *et al*., 2010). Only scientific research fishing and occasional exploratory sets have ever been made deeper.

Controlled exploration for Antarctic toothfish is still expanding around the Antarctic continent, while the fishery for Patagonian toothfish is moving onto sub-Antarctic seamounts in the southern Indian and Pacific Oceans. Otherwise, all plausible areas for productive high seas bottom fishing have already been explored and exploited. Other than a minor increase for the toothfish fishery, further expansion of fishing grounds seems improbable.

RESOURCES EXPLOITED BY BOTTOM FISHING

Variety of resource species

A wide variety of finfish, and some shellfish, have been exploited by bottom fishing in the high seas. As the largest catches have been taken where continental shelves project beyond the boundaries of national jurisdiction, so the principal resources have been drawn from the major resource species of the regions where those shelves occur: Argentine hake, hoki, Argentine shortfin squid and longtail southern cod on the Patagonian Shelf; and Atlantic cod, haddock, various small flatfish and skates on the Grand Banks and the northeast Atlantic high seas grounds. There are also major fisheries for snow crab in the northeast Atlantic and Barents Sea, and to a lesser extent for red crab in the southeast Atlantic. Sebastinid redfish, monkfish and occasionally northern shrimp are also taken on the upper continental slopes of the North Atlantic, and on the Mid-Atlantic Ridge. These are all species which can alternatively be taken at continental-shelf depths in areas under national jurisdiction.

Additional resources are also harvested at upper- and mid-slope depths in the North Atlantic, on the continental slopes themselves but also where suitable depths occur on the Rockall Plateau and the Mid-Atlantic Ridge. There are long-established longline fisheries for ling and tusk (with a valuable addition of Atlantic halibut) in the northeast and for Atlantic halibut in the northwest, each of which is primarily under national jurisdiction but does extend into the high seas. Roundnose grenadier has been the principal trawl-caught resource at mid-slope depths and downwards to 2 000 m, though most of the former grounds are now under national jurisdiction. Other species taken in the high seas include blue ling, black scabbardfish, slickheads, argentines, chimeras and – by an important and very deep fishery in the Flemish Pass –

Greenland halibut. Deepwater sharks are also taken on Rockall Plateau, raising special conservation concerns.

Seamount fisheries are only a minor component of the bottom fisheries of the high seas. The principal resource in warm-temperate zones worldwide is alfonsino, though in the North Pacific catches on the southern Emperor and northwest Hawaiian seamount chains are dominated by pelagic armourhead. At the higher latitudes of the Southern Hemisphere most interest has focused on orange roughy, though it is not primarily a seamount species, and is only truly abundant on the extensive, deep grounds of Zealandia (inside New Zealand's EEZ). Nevertheless, its very high value has led to near-global exploration, which has found fish on various continental slopes under national jurisdiction but only on seamounts from the southwest Pacific westwards to the southeast Atlantic in the high seas.

As those principal seamount resources have been depleted, attention has turned to alternatives: black scabbardfish in the northeast Atlantic; boarfish in the southeast Atlantic; Sebastinids in the North Pacific; rubyfish in the Indian Ocean; plus various oreos and other dories, cardinalfish, trevalla and others across two or more regions. Portuguese dogfish are taken on some seamounts in the southernmost Indian Ocean, and there have been scattered attempts to develop fisheries for deep-living crabs. Precious corals offer a potential high sea resource, but this was only undertaken in the now closed fishery from the Emperor Seamounts of the North Pacific using dredges between the 1960s and 1980s (Clark *et al*., 2007).

Toothfish form the last broadly distributed benthic resource. The greater part of the global catch is Patagonian toothfish, but that is primarily taken from waters under national jurisdiction, on the continental slopes east and west of South America, and around sub-Antarctic islands eastward into the Pacific. Reported landings from the high seas have been small, but in the 1990s there were serious problems of illegal and unreported toothfish fishing in national waters which may have extended into more distant areas; information on the true extent of high seas catches therefore remains limited. The fishery continues on seamounts in the sub-Antarctic zone. Still further south, Antarctic toothfish are taken along the continental margin of Antarctica as well as around some islands. That fishing is considered to be in the high seas, since national claims of maritime jurisdiction in those waters are in abeyance, though often close to either land or an ice shelf.

Three other parts of the World Ocean have their own unique high seas resources: the Mediterranean Sea is distinct from anywhere in the outer oceans in oceanographic, ecological and jurisdictional terms. The high seas fisheries there are often contiguous with coastal fisheries, and dominated by decapod shrimps and European hake. A wide variety of other species are also taken, where deep water lies close to the land and can therefore be fished at a lower cost by smaller vessels. The fisheries of the Saya de Malha Bank in the Indian Ocean are unique among high seas fisheries in both their latitude and depth. The resources there are equally unique, with primarily dame berri and crimson jobfish. Lastly, the Canadian fishery for sablefish is largely confined to waters under national jurisdiction but spills out to some seamounts in the high seas of the northeast Pacific.

DEFINING DEEP-SEA FISHERIES

There have been attempts to define "deep-sea fisheries" in terms of the biological characteristics of their resources. The FAO Guidelines refer to deep-sea fisheries as follows:

> *the total catch (fish and bycatch) includes species that can only sustain low exploitation rates; and the fishing gear is likely to contact the seafloor during the normal course of fishing operations.*
>
> (FAO, 2009)

Bensch *et al*. (2009) note that fishing depth has not been considered a primary criterion, though most of the fisheries considered in the review are conducted at depths below 200 m on continental slopes or isolated oceanic topographic structures such as seamounts, ridge systems and banks.

The overriding conclusion from this survey of the resources exploited by bottom fishing in the high seas is that they have no unifying biological characteristics, save for their association with the seabed. In all other respects, it is the variety of the resource species, rather than any commonality, that is most evident. Nor can any biological characteristic distinguish species harvested in the high seas from those taken in areas under national jurisdiction, since the boundary between the two lacks ecological significance. Indeed, almost all of the targets of high seas bottom fisheries are also harvested in national waters, and in larger quantities.

Relationships with the seabed

While all of the resource species of interest to this review are necessarily associated with the seabed, the degree of that association is highly variable (cf. Parin *et al*., 1997). The species include:

- arctic surfclam, which lives embedded in the sediment (hence "sedentary" in its ecology and under UNCLOS);
- crabs and others that move freely across the seabed but remain in essentially constant contact with it, after settling from their planktonic larval stage (thus "sedentary" under the legal definition of UNCLOS, though not the ecological meaning of that term);
- flounders and others in regular proximity with the seabed but are capable of swimming above it ("benthic" group of Parin *et al*. (1997) – though part of the nekton, not the benthos);
- Atlantic cod and others which commonly swim within a few metres of the seabed but sometimes rise tens of metres above it (near-bottom and off-bottom components of the "benthopelagic" group of Parin *et al*. (1997));
- hoki and others that spend daylight periods very near the seabed but rise into midwater as part of a diel vertical migration ("off-bottom pelagic" group of Parin *et al*. (1997));
- orange roughy and others that, at some life stages form dense, local aggregations which have their bases close to the seabed but which are tall enough so that some individuals within them may be tens of metres above the bottom; and
- alfonsino and others which often live above the bottom but in association with seabed features, such as schooling above the peaks of seamounts.

There are two further groups which fall outside the scope of the present review but merit mention here:

- tunas, mackerels, herrings and others that are strictly pelagic, often epipelagic, though their distributions may nevertheless reflect those of seabed features; and
- particular populations of typically bottom-associated species that have adopted an off-bottom, pelagic existence at depths below the epipelagic zone. Four populations of three species relevant to this review have made that transition: one of blue whiting in the northeast Atlantic, two of redfish in the Irminger Sea and one of walleye pollock in the central Bering Sea. Although fully pelagic, those populations can approach the continental slopes closely enough to sometimes be caught by bottom trawls (as indeed can some strictly pelagic species).

Before 1950, these complexities could be ignored, since fishing gears either had to rest their weight on the seabed or else operate above it. Bottom gears would not deploy properly in midwater, while pelagic gears would equally fail and likely be damaged or lost if they came into contact with the seabed. Resources could thus be classified into either benthic, demersal or pelagic, based on the gears used to harvest them. However, midwater trawling was developed during the 1960s (Sahrhage and Lundbeck, 1992) and subsequent developments in control technology – particularly in acoustic equipment for measuring net altitude – have allowed midwater nets (sometimes designed to survive incidental contact, with break-away footropes) to be fished very close to the seabed. Meanwhile, the aimed trawling developed for seamount fisheries has come to use bottom trawls on sets that often barely touch down. No technology has yet been developed for non-contact but near-bottom fixed gears, perhaps because no benefit to such an approach has been identified. There are however floating longlines which only contact the seabed through weights deployed at intervals along the mainline and in their buoyline anchors.

Thus, it is now possible to harvest such species as orange roughy or alfonsino either on or above the seabed, using bottom or midwater trawls, and the trawlers working in such fisheries are often rigged with both gears so that either may be used, as circumstances dictate. In short, the distinctions between on-bottom and midwater but near-bottom fisheries have become blurred, complicating both the management and understanding of many of the fisheries that fall within the scope of this review.

STATUS OF RESOURCES EXPLOITED BY BOTTOM FISHING

Given the weaknesses in the information available on the bottom fisheries of the high seas, it is not possible to comment on the status of most of their resources with any certainty. This is especially true of those outside the relatively well-studied North Atlantic. For many resources, notably the orange roughy, there is no reasonable doubt that biomass has been depleted far below pre-exploitation levels, but it is less clear whether the resources are now depleted below levels that might support long-term optimum yields.

Past depletions have led to some fisheries being closed and others ending without formal management closure. The resources of most of those are neither monitored nor assessed and no up-to-date comment can be made concerning their status. This section is therefore largely limited to a consideration of those high seas resources which have been fished in recent years, mainly 2014–2016, though comments are included on a few that are currently subject to closure but still routinely assessed.

The status of the resources currently exploited are summarized in Table 2.1, however, most are essentially unknown. The principal resources – those of the Patagonian shelf and the Grand Banks – are thought to be recovering or in generally good condition. The Patagonian shelf resources are all straddling stocks, with high seas catches accounting for only a fraction of the whole stock. By contrast, many of the groundfish resources in the northwest Atlantic were severely depleted during the latter decades of the twentieth century. Of those fished in the high seas, some have partially or fully recovered following strict management restrictions, though not all of them have yet reached a level of biomass that would allow the fishery to re-open. That some resources in the high seas have responded to management measures, recovered and been re-opened to fishing is a positive indication of what RFMO/As can achieve. However, only continental-shelf resources have shown that success to date.

Only in the Mediterranean, where deep fisheries can be pursued relatively close to land, is there firm evidence (derived from analytical stock assessments) of fishing mortality rates vastly exceeding defined targets. Elsewhere, the Canadian longline fishery for Atlantic halibut, along the continental slope eastwards to Flemish Cap, and the Mauritian handline fishery for dame berri, on the Saya de Malha Bank, offer encouragement that high seas bottom fisheries can be sustained over the long term, even though there is little to indicate that either fishery is taking its optimum yield. While the toothfish fisheries under CCAMLR management do not have the same long history, what is known of them promises equal sustainability over the long term.

TABLE 2.1
Status of target resources of bottom fisheries in the high seas, 2014–2016

Region	Species	Resource	Status
NE Atlantic	alfonsino	All areas	unknown
	black scabbardfish	Other stocks	catch stable
	blue ling	SA 5b, 6, 7	catch down
	orange roughy	MAR	depleted, zero TAC
	roundnose grenadier	MAR	catch down
	roundnose grenadier	SA 5b, 6, 7, 12b	catch down
	tusk	SA6b	catch down
	deepwater sharks	All areas	unknown
NW Atlantic	alfonsino	Corner Rise seamounts	unknown
	redfish	Division 3M Flemish Cap	biomass high but trending down as cod rebuild
	redfish	Divisions 3LMNO Grand Bank	biomass high and increasing
	Atlantic cod	Division 3M Flemish Cap	rebuilding from depletion and reopened
	Atlantic cod	Divisions 3NO Grand Bank	rebuilding from past depletion but not yet reopened
	Greenland halibut	Flemish Pass	biomass declining as ecosystem recovers
	thorny skate	Grand Bank and Flemish Cap	unknown
	yellowtail flounder	Southeast Shoal	rebuilt from depletion and reopened
	Atlantic halibut	continental slope	catches and catch rates stable, biomass high
	northern shrimp	Division 3L	biomass declining as ecosystem recovers
	snow crab	Grand Bank	catches and catch rates high but resource predicted to decline as water warms
	Arctic surfclam	Grand Bank	not currently harvested
	Iceland scallop	Grand Bank	not currently harvested
Central Atlantic	alfonsino	seamounts	unknown
SE Atlantic	alfonsino	Valdivia Bank	unknown
	southern boarfish	Valdivia Bank	unknown
	Patagonian toothfish	southern seamounts	unknown
SW Atlantic	Argentine hake	Patagonian shelf	under management
	hoki	Patagonian shelf	under management
	longtail southern cod	Patagonian Shelf	unknown
	Argentine shortfin squid	Patagonian Shelf	under management
	Patagonian scallop	Patagonian Shelf	under management
	Patagonian toothfish	continental slopes	unknown
Mediterranean	"red shrimp"	various	fishing mortality above target
	European hake	various	fishing mortality above target

Region	Species	Resource	Status
N Pacific	pelagic armourhead	Emperor Seamounts	unknown, possibly severely depleted
	alfonsino	Emperor Seamounts	unknown
	rockfish, oreos, mirror dory	Emperor Seamounts	unknown
	sablefish	NE Pacific seamounts	unknown
S Pacific	orange roughy	various	depleted but severity unknown
	alfonsino	various	unknown
	oroes, cardinalfish	various	unknown
	bluenose warehou, hapuku, etc.	various	unknown
	Antarctic toothfish	Hjort Trench, Pacific-Ant. Rise	unknown
Indian Ocean	dame berri	Saya de Malha	catch rates stable, catches below estimated MSY
	crimson jobfish	Saya de Malha	unknown
	alfonsino	seamounts	unknown
	orange roughy	seamounts	depleted but severity unknown
	rubyfish	seamounts	unknown
	ocean blue-eye trevalla	seamounts	unknown
	Portuguese dogfish	southern ridges	unknown
	Patagonian toothfish	southern ridges	unknown
Southern Ocean	Patagonian and Antarctic toothfish	Ross Sea and others	under cautious development

Colour code: dark green (good evidence of positive status); light green (weak evidence of positive status or good evidence of weakly positive status); light red (weak evidence of resource-conservation concerns or good evidence of weakly negative status); dark red (good evidence of negative status); blue (limited or no evidence of status).

An assessment of stock status with a single metric is subjective and problematic. This assessment places more emphasis on stock biomass (*B*) and less on fishing mortality (*F*). Stock recovery is dependent upon good environmental conditions and low fishing mortality. Assessments can change quite rapidly. See regional chapters for details.

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3. High seas bottom fisheries

HIGH SEAS BOTTOM FISHERIES

This review provides an update to the first *Worldwide Review of Bottom Fisheries in the high seas* by Bensch *et al.* (2009), which was based on information collected in 2003–2006. A greater quantity and quality of information is now available on bottom fisheries and their catches in the high seas, though it is still incomplete. This is partly due to inconsistent reporting in some regions, and partly due to information being provided at the stock level without necessarily disaggregating catches into high seas and national jurisdictions. Furthermore, the distinction between bottom- and near-bottom fisheries is often vague, with the distinction being made based on whether the gear touches the seafloor during the normal course of operations. Disaggregation is not important when assessing stock status, but it is when considering possible impacts to benthic habitats.

A detailed account, based on information existing in the public domain, is provided in the regional chapters. While every attempt has been made to ensure the information provided is accurate, the complexity of the fisheries and the reporting often make such tasks difficult. For the most part, catches (usually landings), are formally reported by flag states, and these official figures have generally been used except where stated otherwise. Maps depicting the location of fisheries have occasionally been gleaned from sources intended for other purposes; these must therefore be treated with caution and the original sources should be consulted in order to provide both clarification and updates, given that new distributions are regularly provided by RFMOs. Although data gaps have not been highlighted in this review it is hopefully clear when they exist, as little to no information is provided. The year 2016 has been chosen in an attempt to provide a global high seas catch by bottom fisheries.

There is a general misconception that over-exploitation in shallower waters led to the development of deep-sea fisheries. While this may be the case for small downward extensions in fishing depth, the true deep-sea fisheries required different technologies. These technologies followed several strands of development as increasing electronic sophistication allowed for improvements in locating fish aggregations and accurate gear deployment. Bottom fishing in the high seas underwent a major expansion between 1957 and about 1980, but has been generally contracting since the turn of the century and seen no real expansion in the range of depths fished since 1990.

CATCHES AND THEIR DISTRIBUTION

Regional distribution

The global catch from bottom fishing in the high seas in 2016 was estimated at 225 924 tonnes. However, this estimate must be regarded as a minimum, representing about 0.3 percent of the total global marine catch in 2016, which amounted to 79 300 000 tonnes and was made up primarily of demersal, small pelagic, large pelagic and cephalopod species (FAO, 2018). For most high seas regions, the small and large pelagic fisheries provide a substantially higher catch than the demersal species.

The majority of the high seas demersal catches in 2016 were taken in the northwest and southwest Atlantic. Catches in the northwest Atlantic and Mediterranean were boosted by high crustacea catches – mainly snow crab and deepwater shrimp, respectively. Catches in other regions were smaller in terms of volume but important in terms of value, insofar as the demersal species targeted often command high premiums. Catches of demersal elasmobranchs were significant in the Indian Ocean and North Atlantic, but much less fished elsewhere (Table 3.1).

About half of the overall catch was taken under the Spanish flag, largely because of the dominance of that one state in the high seas bottom fisheries on the Patagonian Shelf, though trawlers from Spain were also responsible for about a quarter of the northwest Atlantic catch. Portuguese trawlers took more from the latter region than the Spanish did, but were otherwise little involved in the high seas fisheries. No one other flag state made a major contribution to the global total.

TABLE 3.1
High seas bottom fisheries catches (tonnes) in 2016, by region

Region / Group	NW Atlantic	NE Atlantic	Central Atlantic	SW Atlantic[1]	SE Atlantic	North Pacific	South Pacific	Indian Ocean	Southern Ocean	Mediter-ranean Sea	Totals
Finfish -teleosts	52 324	7 418	0	54 968	60	6 589	1 510	5 934	4 408	32 026	165 237
Finfish - elasmobranchs	3 754	400	0	0	0	0	0	1 800	0	0	5 954
Crustacea	742	13 726	0	0	0	0	0	0	0	25 216	39 684
Molluscs – Cephalopods[2]	0	0	0	15 049	0	0	0	0	0	0	15 049
Totals	56 820	21 544	0	70 017	60	6 589	1 510	7 734	4 408	57 242	225 924

[1] 2014 value.
[2] Includes the very low landings of other molluscs from some regions.

Target species and fishing depths

The principal fisheries and their approximate operating depths are given in Table 3.2. Bottom trawls can operate commercially down to some 1 500 m; they are capable of going much deeper, but the shooting and hauling times rather limit the profitability. The use of these gears is limited by bottom topography: they require fairly smooth ground so that the gear does not foul, but can with skill and care be fished on slopes. The other main gears are longlines and pots, and these are typically fished on rougher ground, from shallower water down to around 2 000 m. The choice of gear is also dependent upon the target species and the RFMO and/or flag state measures in place. It must be stated that bottom or even deep-midwater trawling on seamounts is a highly skilled and targeted process, with bottom times often in the 15–30 minute range over well-known, previously trawled grounds.

The shallowest high seas fisheries are in the Indian Ocean around the Saya de Malha Bank; here operations take place at less than 100 m depth using bottom trawls, pots and longlines fishing for sky emperor and other species. There are also some shallow fisheries around the Southeast Shoals of the Grand Bank and the top of the Flemish Cap. Many, but not all, of the fisheries are at 200–500 m depth and these can be very productive. Seamount fisheries can be relatively shallow at 300–400 m, as in the North Pacific, or much deeper, as in the northwest Atlantic, the Indian Ocean and Southern Ocean. The latter only has deep longline fisheries for toothfish in the high seas (Table 3.2).

Relation to other fisheries

The boundary of the high seas is an important one in law but of no consequence either ecologically or to the resources. Its significance to fishermen, fishing and the fisheries is more variable. Canadian crabbers can largely ignore the boundaries that cut across the snow crab grounds in their respective regions, since these resources are regarded as sedentary and under national jurisdiction. Fishing on finfish and cephalopods in the high seas requires additional licenses, usually issued by flag states under joint

TABLE 3.2
Catches (tonnes) by major and notable high seas bottom fisheries in 2016, by region, depth and species

Region	Primary depth zone (m)	Principal target species	Catch
Northwest Atlantic	50–400	Atlantic cod, flounders, thorny skate, etc	244 900
	200–500	redfish	21 671
	< 200	snow crab	742
	200–500	northern shrimp	0
	≤ 900	Atlantic halibut	543
	700–1 300	Greenland halibut	8 615
Northeast Atlantic			
– Barents sea	150–300	snow Crabs, shrimp, cod, Greenland halibut	17 794
– Rockall and Hatton banks	200–600	haddock, ling, scabbardfish, tusk, etc	3 161
– Mid-Atlantic Ridge and seamounts	600–1 800	grenadiers, alfonsino, orange roughy	589
Mediterranean Sea	400–800 m	"red shrimp"	25 216
	300–500 (50–300)	hake (includes shallower water hake)	19 736
Southwest Atlantic	< 300 m	longtail southern cod, Argentine hake, hoki, Argentine shortfin squid	68 000
	> 1 000	Patagonian toothfish	1 941
Southeast Atlantic	800–1 500	Patagonian toothfish	60
North Pacific	300–400	pelagic armourhead, alfonsino, oreos	6 434
South Pacific	< 700	bluenose warehou and others	227
	700–1 500	orange roughy, oreos, cardinalfish	1 086
Indian Ocean	20–60	sky emperor, etc	unknown
	700–1 500	orange roughy, alfonsino	5 034
	> 300	deepwater sharks	1 800
Southern Ocean	1 000–1 600	toothfish	4 166

agreements with RFMOs. The process for acquiring licenses is usually sufficiently complex to deter many fishers from having permissions to fish in the high seas, and so they restrict their activities to national waters. There are many major fisheries in which resources freely overlap between the high seas and waters under national jurisdiction, but fishermen may not. With such a variety of relationships, it would be too simple to suggest that all high seas bottom fisheries are simply extensions across legal boundaries of fisheries that are primarily under national jurisdiction. The straddling nature is an important aspect of the fishery and its management.

Distant-water fisheries

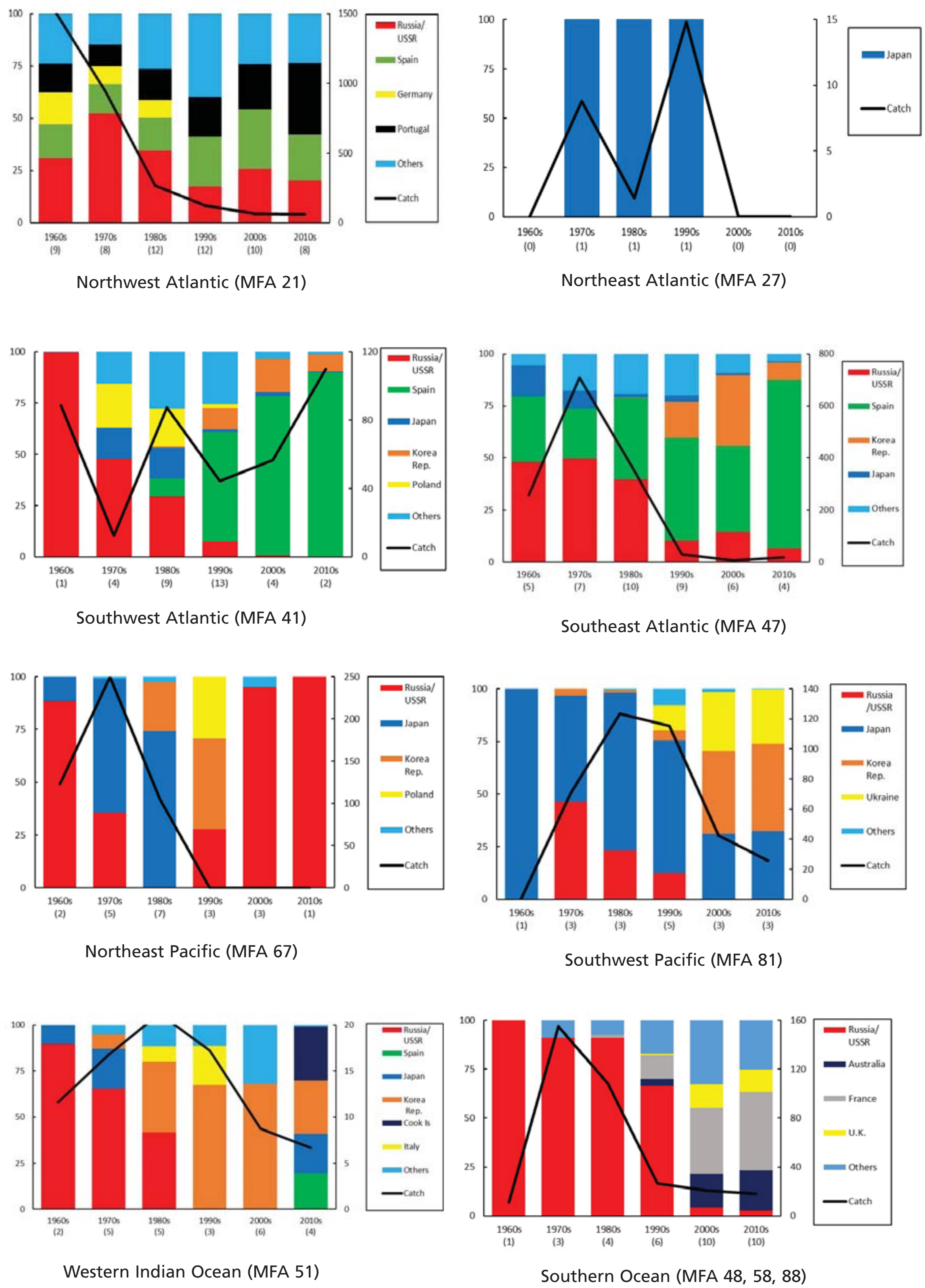
Distant-water fisheries – fisheries which operate far from their flag states' home ports – have been active since the beginning of the 1900s, when European vessels fished the Grand Bank of Canada. These fisheries usually operated outside of national waters, typically set at 12 nautical miles off the coast, and fished the productive continental shelves and slopes. Following UNCLOS, from 1979 onwards many states claimed an extended economic zone (EEZ), extending up to 200 nautical miles off the coast. Though this process is still ongoing, most states had established EEZs by the end of the 1980s. This considerably reduced the fishing opportunities of distant-water fleets. However, bilateral agreements do exist that allow distant-water fleets to fish within the national waters of other states. This makes it very difficult to determine high seas catches. While it is possible to identify which flag states operate distant water fisheries and to estimate their catches, they cannot be reliably partitioned into EEZs and high seas catches.

The FAO FishStatJ dataset provides national landings of finfish and shellfish caught in the FAO major fishing areas (MFAs) (FAO, 2019). These areas combine catches from national waters, EEZs and the high seas. In order to gain insight into distant-water fisheries, MFAs were outlined to correspond approximately to the convention/regulatory areas established by the RFMOs managing deep-sea fisheries. The landings of "demersal marine fish" (a FAOSTAT grouping within FishStatJ) from 1960 to 2017 for all states except the coastal states of the MFA were examined. This removes landings from catches taken in national and EEZ waters of the relevant coastal state and produces a dataset that corresponds to distant-water fleets. The more obvious pelagic species were removed from the dataset (mostly large pelagic sharks which for some reason were included in this demersal FishStatJ grouping) and shellfish were not included in the analysis. No states were removed from the dataset for the Southern Ocean as all fisheries there can be regarded as distant-water fisheries far from any home ports. There was no recorded fishing on demersal species by non-coastal states in the Mediterranean regions and so this region was excluded. The resultant dataset and associated graphics provides insight into catches by distant-water fleets (Figure 3.1) but does not constitute a record of high seas catches because the coastal states' high seas catches have been removed, and the "high seas" area changed after the establishment of EEZs and bilateral agreements relating to EEZ waters. High seas catches are provided in the individual regional chapters to the extent known.

Catches by non-coastal states increased in all regions, except the northwest Atlantic where a fishery was already developed, throughout the 1960s and 1970s, and then showed often dramatic declines from the 1980s onwards, owing to the establishment of EEZs (Figure 3.1; Table 3.3). This was due to a combination of overfishing reducing stock biomass and a switch to coastal states taking the fish. The pattern in the southwest Atlantic is slightly different as the current high seas fisheries are very productive but small in terms of the area fished; they also target straddling stocks that resides almost entirely in waters under national jurisdiction.

The number of non-coastal states fishing in the selected regions has also shown great changes as distant-water fisheries developed and then declined. Generally, the number of States with distant-water fleets has decreased with many regions having only a few distant-water states fishing (Figure 3.1, numbers in parentheses). Japan is the only country to have had a demersal fishery in the northeast Atlantic from the 1960s to 1980s. All other regions have had several non-coastal States fishing, with the most significant changes being the fishing patterns of the former Union of Soviet Socialist Republics (USSR) / Russian Federation, who were active in the southwest and southeast Atlantic, South Pacific, Indian and Southern Oceans in the 1960s–1980s, but largely ceased distant-water fishing owing to reduced stocks and national restructuring. The occurrence of Russian Federation fishing on the eastern side of the North Atlantic is an artefact of the statistics, with small reported catches in 1990, 1991 and 2002 only. The distant-water fleets of Japan and the Republic of Korea have fished more consistently through the time period examined, with the latter more active around the 1990s and 2000s. Spain continues to have distant-water fleets, often fishing under bilateral agreements, and on more productive species such as hake, on both sides of the southern Atlantic. The Republic of Korea also remains active in some areas, mainly in the southwest Atlantic, Indian and Southern Oceans. The Southern Ocean continues to have a large number of states fishing a wide variety of species including rockcod, icefish and toothfish (see Figure 3.1).

FIGURE 3.1
States involved in distant-water fishing operations for demersal finfish species in FAO Major Fishing Areas (MFAs)



Coastal states were removed from the analysis.
Left axis: percent catch in decadal period; right axis: catch ('000 tonnes); total number of flag states involved in parentheses.
Source: FAO, 2019.

TABLE 3.3
Global average annual landings (tonnes) of demersal finfish species caught by distant-water fleets in high seas and EEZ waters for successive ten-year periods

State	1960s	1970s	1980s	1990s	2000s	2010s[1]	Average
former USSR / Russian Federation	809 993	1 123 521	403 204	59 663	18 921	11 937	418 078
Spain	244 637	141 534	60 291	54 112	63 280	115 338	113 125
Japan	55 990	265 085	192 793	80 732	18 330	10 874	107 177
Poland	47 203	86 905	139 201	190 663	5 434	524	81 004
Portugal	208 240	117 832	65 830	24 410	14 069	17 617	76 633
Germany	233 340	93 758	27 581	3 803	2 480	1 944	62 503
France	140 412	36 176	21 265	3 339	7 043	7 259	36 904
Republic of Korea	0	4 132	44 739	33 095	35 565	24 558	23 651
Faroe Islands	74 371	19 588	4 682	2 595	1 026	2 941	18 037
Norway	45 407	17 941	1 986	12 822	2 273	3 089	14 293
Others	65 390	88 948	94 699	70 067	33 696	22 657	63 953
Total	1 924 983	1 995 420	1 056 270	535 299	202 116	218 739	1 015 358

Coastal State catches excluded.
[1] 2010–2017 only.
Source: FAO, 2019.

The state most involved in distant-water fishing of deep-sea demersal species from 1960 to the present is the former USSR/Russian Federation, taking annual averages of around 400 000 tonnes over that time period, mostly from catches in the 1960s and 1970s when annual averages were around 1 000 000 tonnes. Spain, Japan, Poland, Portugal and Germany each took annual averages of 80 000–110 000 tonnes, which again came mostly from catches in the same, earlier period, though Japan and Poland also had substantial catches in the 1980s–1990s. Catches in distant-water fisheries have shown a marked downward trend since the peaks in the 1960s–1970s, dropping to a tenth of these levels in the current decade, when 60 percent of catches came from Spain's distant-water fleets with an average annual distant-water catch of over 110 000 tonnes. Portugal, the Republic of Korea, the Russian Federation and Japan each averaged 11 000–24 000 tonnes annually. In terms of distant-water effort, since the 1960s the former USSR/Russian Federation, Japan, the Republic of Korea, and Spain have fished in seven, six, five and four major ocean regions respectively, representing extensive coverage by these four states (Figure 3.1). However, Spain – and to a lesser extent the Republic of Korea – are the only states to continue their widespread distant-water fishing operations on deep-sea demersal species.

The main distant-water states fishing for demersal species in 2016 (the focus year of this report) align with the decadal averages shown in Table 3.4. The northwest Atlantic and the Southern Ocean are the regions where most distant-water fleets are concentrating, and the southwest Atlantic is where the highest catches occur. Spain is catching the bulk of the demersal fish, with Portugal, the Republic of Korea, the Russian Federation and Japan making significant contributions.

It should be noted that this sub-section shows only catches of demersal finfish species for distant-water fleets operating far from their home ports and fishing mainly in international waters – typically 12 nautical miles prior to the 1980s and 200 nautical miles thereafter – though this could be modified by bilateral fishing arrangements. Catches from coastal states in the respective FAO MFAs are not included. While the catch values shown in this section cannot be compared with those given for the high seas elsewhere in this report, they do provide an insight into the changes that have happened to distant-water fleets.

TABLE 3.4

Landings (tonnes) of distant-water fleets in 2016 catching demersal species in selected FAO major fishing areas

FAO MFA[1]	21	27	41	47	67	81	51	48 58 88	Totals
States	NW Atlantic	NE Atlantic	SW Atlantic	SE Atlantic	NE Pacific	SW Pacific	W Indian Ocean	Southern Ocean	
Spain	10 342		85 984	5 712		13	2 398	435	104 884
Portugal	19 527		3	13		5	52		19 600
Republic of Korea			13 573			84		861	14 518
Russian Federation	10 529			246				740	11 515
Japan	913			61		7 030	2900	190	11 094
France								7 644	7 644
Australia								3 827	3 827
Faroe Islands	3 566								3 566
Norway	3 210							6	3 216
United Kingdom	1 209		190				13	1 792	3 204
Estonia	3 121								3 121
Germany	1 902								1 902
New Zealand								1 431	1 431
Others[2]	0		125	1 372		0	0	1 604	3 101
Totals	54 319		99 875	7 404		7 132	5 363	18 530	192 623

[1] FAO MFA - FAO major fishing area (includes the high seas, EEZs and territorial waters). Catches by coastal states bordering the MFAs are not included. (*Source*: FAO, 2019).

[2] Others include southwest Atlantic (Ukraine 125 tonnes); southeast Atlantic (Falkland Islands (Malvinas) 875 tonnes; (Poland 465 tonnes); Southern Ocean (Ukraine 453 tonnes; Chile 452 tonnes; South Africa 375 tonnes; Uruguay 322 tonnes).

FISHING TECHNIQUES AND TECHNOLOGIES

Major gear types

In terms of the tonnage caught, the high seas bottom fisheries of 2016 overwhelmingly used otter trawls. Some fisheries used bottom and midwater trawls interchangeably, harvesting the same bottom-associated resources. No high seas bottom fishery uses beam trawls. The high seas Southern Ocean fisheries are exclusively longline, a gear type that accounted for about a third of the Indian Ocean catch, plus a substantial fraction of what was taken in the South Pacific and southeast Atlantic, but only made much smaller contributions in other regions. There were pot fisheries for crab, especially snow crab in the North Atlantic, which accounted for a considerable weight of catch, though much of that was shell weight. A minor amount of gillnetting featured in various regions.

Specific gear types and techniques

There have been various attempts to describe the special gears or techniques used in “deep-sea” fisheries, but what is certain is that there is nothing universal to all high seas bottom fisheries, nor anything unique to that group of fisheries. Every fishery must, of course, use specialized harvesting methods that are adapted to the resource, the environment, economic constraints, market demands and more. Whether in the deep trawl fishery for Greenland halibut in the northwest Atlantic, seamount trawling for orange roughy in the South Pacific and Indian Oceans, or the longline fishery for Patagonian and Antarctic toothfish around the Southern Ocean, each calls for a very different approach. However, as almost all high seas fisheries straddle the boundaries of national jurisdictions, so their gears and techniques are also used in fishing under those jurisdictions.

ORIGINS AND DEVELOPMENTS

The prolonged development that has led to the modern high seas fisheries has several roots and many drivers. Most importantly, seafood is among the most perishable of all traded goods. The emergence of commercial – as distinct from subsistence – fisheries thus required the development of means for the preservation of fish so that they could be transported to markets far away from the fishing locations. For example, Atlantic cod became a prime distant-water target species because the composition of its flesh facilitated long-term preservation through various combinations of salting and drying.

The emphasis in this review is on sea areas that are now termed the high seas, though these areas had no delimited designation prior to the establishment of EEZs. The boundaries which delimit high seas bottom fishing today did not begin to emerge until 1967; the majority were established a decade later. Moreover, the most recent change of relevance to this review came in 1997 – when the United Kingdom declared Rockall to be an uninhabitable rock, hence withdrawing its claim to jurisdiction over waters 200 nautical miles west of that islet. Therefore, the boundary lines which shape the account presented here did not apply to most of the fishermen who lived through the developments described. Furthermore, the fisheries in what are now the high seas were always embedded within larger industries that mostly worked closer to land – as remains true today. They both drew from, and contributed to, the development of the totality of global fisheries. As a result, this account cannot be confined strictly to high seas fisheries.

Before steam trawlers

Early fisheries were restricted to nearshore waters by the requirement to land their catches for preservation ashore, often within hours of capture. That remained true even of migrant fisheries, in which fishermen travelled great distances from their homes to the fishing grounds but then worked out of adjacent harbours – Norway's Lofoten cod fisheries were the prime example in Medieval Europe. The development of techniques for the onboard preservation of the catch was necessary before offshore fishing could begin, including fishing in the modern high seas. Among European nations, that step was taken by the Dutch during the early fifteenth century, when they initiated a pelagic fishery for Atlantic herring in the first instance, followed by bottom fishing for Atlantic cod (Sahrhage and Lundbeck, 1992). They did not, however, need to go outside the North Sea and so did not reach the modern high seas.

While the fisheries for Atlantic cod on Grand Bank were the first to work so far from land, originally they only fished in shallow water. The *pêche verte* was confined to depths of less than 100 m, while the later schooner fishery did not set longlines much deeper than 200 m (de la Morandière 1962–66; Rathbun 1887). Far deeper fishing had, however, been developed close to other coasts long before. Many Polynesian communities fished for oilfish and other deep-living species at depths down to 400 m, using a distinctive gear known to anthropologists as a "*Ruvettus* hook". The widespread use of that gear suggests that the fishery began a millennium ago, before Polynesian dispersal across the Pacific, though that dating remains uncertain (Hooper, 1991). Vertical-line fisheries for oilfish, using modern gears, continue in the Pacific and have been developed by island nations in the Indian Ocean during recent decades. European fishing at similar depths began by the sixteenth century, when Norwegian fishermen worked the Storegga ground at depths of 150–400 m for ling and tusk. That fishery continued until the late nineteenth century, when it was replaced by longlining, which spread to new grounds, eventually reaching the modern high seas on the Rockall Plateau after 1945 (Bergstad and Hareide, 1996). Other deep, nearshore, vertical-line fisheries emerged later, often around oceanic islands, where steep seabeds make great depths accessible for fishermen in small boats. Such fisheries included one for black scabbardfish off Madeira, which commenced in 1839 and later spread as far as mainland Portugal (though its hooks are deployed near, not on, the bottom: Leite, 1989; Martins and Ferreira, 1995). A similar fishery, though for alfonsino, began off the Japanese coast before 1875. A century later, that briefly expanded to the seamounts of the northwestern Hawaiian Ridge, until that area fell under national jurisdiction from 1977 (Seki and Tagami, 1986).

Bottom fishing at great depths in what are now the high seas began on the continental slopes around Grand Bank and Flemish Cap. Its genesis lay in another of the drivers of fisheries development: human food choices. Those are often only explicable by invoking acquired tastes, social conventions and similar factors (cf. Starkey, 2012).

During the early nineteenth century, the seaboard cities of the United States of America were becoming more cosmopolitan and their populations chose more varied diets. Demand in Boston (and later other cities as railway connections were completed) led to Massachusetts fishermen turning away from the production of salt cod and onto fresh fish. Handlining for Atlantic halibut on Georges Bank began in 1830. Catches grew swiftly to a peak in 1847–1848 then suddenly collapsed, but the fleet expanded its operations northeastward, causing a sequential depletion of its resource as it proceeded. The longer trips demanded that the fish be preserved and halibut do not salt well. The solution, from 1846, was to fit the schooners with "ice houses", using ice harvested in winter from New England lakes by a then-emerging ice industry. The expanding fishery reached the modern high seas, on Grand Bank, by 1870 but still fished in the shallows. From 1873, halibut were found to live deeper than had been supposed and, by 1881, they were fishing down to 750 m, with exploratory sets made to 1 300 m, as well as eastwards to Flemish Cap (Goode and Collins, 1887; Rathbun, 1887) – and thus initiating deep fishing in the modern high seas. The movement to depth was a clear response to depletion in the shallows but it was a depletion of the same Atlantic halibut population, followed by movement of the fishery onto the core of the resource's distribution. Because of the species' complex spatial structure, the inevitable, population-wide "fishing up" process took the form of sequential depletions of local areas, but was still an unavoidable part of the development of the resource. Although much reduced, and taken over by Canadian fishermen after 1920, the Atlantic halibut longline fishery has continued on the continental slope ever since, while working as deep as 900 m (Kenchington and Halliday, 1994; Kenchington *et al.*, 1994; Kenchington, 1996). The vessels have long-since been fully motorized and the gear modernized, but it remains essentially the same fishery, one that has now been in progress for 140 years.

Wetfish and saltfish trawling

Wetfish

Bottom-tending, mobile fishing gears have been known since antiquity (Sahrhage and Lundbeck, 1992) but they tend to take large catches of species, such as flounders, shrimps or oysters, which could not readily be preserved for transport to market. A combination of improved trawls and trawling smacks, turnpike roads, high prices during wartime (facilitating expensive transport by pack pony) and a new proclivity for seaside vacations (which moved urban consumers into coastal fishing villages) led to an expansion of English beam trawling from the late eighteenth century. Then, during the 1840s, a major new fishery emerged in the northern North Sea when the new railways offered subsidized inland transport of fish to feed the industrial workforce, thus increasing the production of manufactured goods. The seaward transport of these goods then generated profits for the railway companies. The adoption of icing – using the New England precedent – allowed longer trips, and the advent of fuel-efficient compound engines facilitated economically viable steam trawling from the 1880s. The steady speeds provided by mechanical propulsion then facilitated otter trawling, initially using the Granton trawl invented in 1892, which allowed both faster trawling and the targeting of more active species. English steam trawlers expanded their operations to the Iceland grounds in the 1890s, the Barents Sea from 1905, Greenland by 1914, then Bear Island, Svalbard and Novaya Zemlya in the 1920s, when Arctic warming made the latter grounds temporarily accessible (Sahrhage and Lundbeck, 1992; Robinson, 1996, 2000, 2009).

Economic viability constrained the steam trawlers to using ports which offered cheap coal, local availability of the many trades and facilities needed to maintain steam machinery, plus dock facilities which allowed swift unloading, space for the vessels to lie afloat even at low tide, and yet the ability to enter or leave almost regardless of wind and tide. Unlike the transoceanic cargo trades, fishing could rarely pay the enormous costs of such engineering works and hence steam trawling came to be concentrated in the few ports where the required facilities were available – with Hull and Grimsby coming to dominate not only the British but the global trawling industry (Jarvis, 2000). In the 1880s, however, two separate ventures constructed modern dock facilities in failed efforts to draw cargo trade from the port of Liverpool, one in Fleetwood, Lancashire and the other in Milford Haven, in westernmost Wales. After 1890, both sought some return from their unused assets by attracting steam trawlers (Jarvis, 2000). Based on the west coast of Britain, the new fleets focused on European hake (Alward, 1932), the principal groundfish resource species of those waters and one exploited since Medieval times (Childs and Kowaleski, 2000). Expansion and serial depletion followed as the trawlers developed the fishery throughout the range of the resource. By 1908, they worked from the Porcupine Bank, west of Ireland, to off Cape Blanco, Morocco – landings reaching 45 000 tonnes the following year. Beginning in about 1905, the trawlers also moved into deeper water, working the upper continental slope down to 450 m depth and, by 1930, down to 550 m – in the process initiating deep-water trawling (Jenkins, 1920; Alward, 1932; Hickling, 1935). The merluccid hakes have remained important resources for the fisheries of the outer continental shelves and upper continental slopes in temperate regions of the World Ocean ever since.

Further deep trawling came with the development of redfish resources, commenced by the German fleet before it was driven from the seas in 1914 but only intensively pursued in the aftermath of war, during the 1920s (Sahrhage and Lundbeck, 1992; Magnússon, 1998). Catch rates were found to increase as the trawlers worked deeper (Lundbeck, 1955), the major ground developed being the *Rosengarten*, a terrace on the ridge between Iceland and the Faroe Islands, at depths of 400–500 m. Trawlers of the former USSR meanwhile took large catches of redfish from continental slopes in the Barents Sea, beginning in 1930 (Maslov, 1944). Together, they established the trawling of long-lived, deepwater resources which would become an international policy concern three-quarters of a century later.

Northeast Atlantic redfish landings reached 105 000 tonnes in 1938, but the fisheries almost ceased during the Second World War (Björnsson and Sigurdsson, 2003). Renewed expansion after 1945 saw the development of other grounds, including on the Reykjanes Ridge (Lundbeck, 1955). Annual catches from the northeast Atlantic peaked at over 200 000 tonnes (Björnsson and Sigurdsson, 2003). Those from bottom fishing have since fallen to much lower levels, while the fishing industry has turned to fully-pelagic populations of the same species complex, primarily in the Irminger Sea (e.g. Sigurðsson *et al*., 2006).

Until the 1950s, those fisheries were confined to "wetfish" trawling, meaning that the catch was held on ice. That imposed a spatial constraint since, for economic viability, a trawler must be able to fill her hold quickly enough to leave time to steam home, before the first fish caught have deteriorated so far as to be condemned for human consumption. When catch rates were high, it was possible to meet that criterion while fishing the West Greenland grounds or in the Barents Sea. Grand Bank proved to be too far from European landing ports. The geographic arrangement of coasts, islands and bathymetric contours is such that all, or almost all, of the grounds then available to the "wetfish" fleets now lie under national jurisdictions.[1]

Salting

It fell to the French to develop trawling in the high seas, where they had commenced high seas handlining nearly 400 years before. Late in the 1890s, Newfoundland restricted bait sales in order to limit the competition for salt cod in international markets. The French longline fleet had to spend time catching its own bait, which encouraged experiments in catching fish for salting using otter trawls; despite the lower quality of the fish, these began in 1904. The development of the fishery was then interrupted by war in 1914 but resumed after 1919 – aided by the invention of Vigneron-Dahl trawls in 1921, which separated the wings from the otter doors, allowing higher headline heights and increased the herding of the fish into the path of the net. The trawlers deliberately avoided the old shallow grounds, which were littered with lost anchors and old wrecks, and went as deep as 400 m (in the modern high seas), where they found the cod concentrated in early spring. The fish were split and salted aboard, then landed for drying ashore, as in the schooner fisheries. At first, the trawlers would land in St. Pierre, returning home only at the end of the season (de Loture, 1949). By 1938, when French catches of cod in the northwest Atlantic reached 153 000 tonnes (Côté, 1952), a new form of very large (1 600 gross registered tonnage, diesel-powered trawler had sufficient endurance to work Grand Bank on trips that lasted several months, originating from ports in metropolitan France (de Loture, 1949; Gueroult,). That fishery continued into the 1970s.

Spanish trawlers joined the French from 1927 – the first distant-water fishing under the Spanish flag in two centuries or more. The fleet was expanded by the Franco regime after it came to power, as a means of encouraging the national shipbuilding industry and hence also the production of steel and coal. In a separate initiative, a fleet of *parejas* was built to harvest European hake in the Bay of Biscay and Celtic Sea. While other nations were at war that fishery did well but the over-expansion of the fleet, combined with falling catch rates, led to the *parejas* being redirected to Grand Bank and the salt cod fishery from 1950 (García-Orellán, 2010; López Losa and Amorim, 2012). Those were the beginnings of the Spanish fleets which now dominate the global high seas bottom fisheries. The Portuguese *Estado Novo* government also encouraged trawling from the 1930s, alongside the dory-schooner fleet (Cole, 1990; López Losa and Amorim, 2012), while there were some Italian trawlers on Grand Bank from the 1930s (McKenzie, 1946) until 1954. All three nations had long been importers of salt cod, which were important parts of their respective national diets. Replacing those imports with national catches was consistent with the broader objectives of autarky, which was adopted in varied forms by the fascist governments of the time.

Freezing

Otter trawling was slow to be accepted in New England and Atlantic Canada but the Massachusetts fresh fish industry did slowly adopt the technology from 1900 and especially after 1920. There was also a small number of steam trawlers out of Nova Scotian ports in the 1920s and 1930s, which were able to supply their limited markets without steaming as far as Grand Bank. New England was, however, a centre for the development of freezer technology. The quality of redfish deteriorates when held on ice for long and, while their fillets may have been accepted by consumers in Germany

[1] Some of the trawling off Novaya Zemlya in the 1920s may have fallen within what is now the high seas "Loophole" in the Barents Sea. Some on the Reykjanes Ridge after 1945 may have been outside Iceland's EEZ.

and the former USSR, the American redfish fishery only grew with the development of the multiplate freezer (introduced in 1933) and the spread of refrigeration through the marketing chain and into domestic settings, which made the sale and consumption of frozen fillets viable (Mayo, 1980). Landings from Georges Bank and the western Gulf of Maine barely surpassed 100 tonnes in any year before 1934 but reached 30 000 tonnes in 1936 and peaked at 60 000 tonnes in 1941 (Côté, 1952; Mayo, 1980). After 1945, the fishery moved east and north, into what is now the Canadian EEZ.

The acceptance of frozen fillets on the American market opened up a new opportunity for Newfoundland, which had lacked the rapid transport links needed to supply fresh-fish markets. The island's economy (not part of Canada until 1949) had been very limited before the war and, from 1945 government policy emphasized economic and social development. Modernization of the fisheries meant trawlers, filleting plants and the export of frozen fillets, with an emphasis on redfish, flounders and haddock (Crowley *et al*., 1993; Andersen, 1998; Gough, 2007). The new fishery had begun by 1947 and by 1953 was landing redfish from the Tail of Grand Bank (Côté, 1952), where the redfish grounds remain outside national jurisdiction and at depths down to 400 m (Martin, 1961).

Factory-freezer trawlers and global expansion

Factory-freezer trawlers

The after-effects of the Second World War drove the global expansion of high seas bottom fishing. FAO was founded in 1945, with the aims of

> *raising levels of nutrition and standards of living […], securing improvements in the efficiency of the production and distribution of all food […], bettering the condition of rural populations, and thus contributing toward an expanding world economy*
>
> **(FAO, 1945).**

The expansion of the world's fisheries was part of those wider goals, offering a key source of animal protein that was believed to be virtually limitless at the time. Improvements in radar, sonar (and hence echosounders) and electronic navigation systems during the war meant that by the 1950s this improved technology was available for civilian use.

One Scottish company, Christian Salvesen of Leith, had been uniquely affected. Before the war it had become the principal operator of pelagic whale-factory ships, but all of these were lost while on war service (mostly as tankers). Depletion of the whale resources during the 1930s made building new ships for that fishery an uninviting investment, so Salvesen sought an alternative application of its expertise with stern-ramp factory ships. The company thus sponsored a series of experiments, beginning in 1947, which combined basic concepts from the whaling industry with a new mechanization of both the handling of trawls on deck and the processing of catches. The end result was the first efficient factory-freezer trawler: *Fairtry*, of 2 600 GRT, launched in 1954. Free of the range limitations of "wetfish" trawlers, she was deployed to the northwest Atlantic (Robinson, 2000). Such ships were also free of the limitations that affected the old side-trawlers: shooting and hauling their gear while head to wind and sea, they could work under worse weather conditions, while the processing of their catches in enclosed spaces allowed them to work where cold air temperatures would freeze fish left on deck before they could be headed and gutted. For deep fisheries, the new design had an additional advantage, in that species of unpalatable appearance or texture, and those which deteriorated quickly on ice, could be swiftly processed into human food, thus expanding the variety of resources that could be targeted.

At that time, the former USSR had a particularly urgent need to feed its people, after a series of disruptions to its national food supply. As early as 1913 the former USSR had identified marine fishing as an important contributor to its future food supply and the government of the former USSR had pursued that goal from 1930, seeing seafood as free from the intermittent droughts which plagued agriculture (Helin, 1964; Österblom and Folke, 2015). After 1945, a new fleet of side trawlers and smaller vessels was swiftly acquired, many of which were commissioned from British yards (Cushing, 1988). By 1950, the fishing out of Murmansk had expanded to Svalbard and onto deeper redfish grounds on the continental slope, while the fleet out of Vladivostok worked the Bering Sea from 1955, including with a deepwater fishery for Pacific Ocean perch, a close relative of Atlantic redfish (Sahrhage and Lundbeck, 1992; Österblom and Folke, 2015). A British attempt to win orders from the former USSR for copies of *Fairtry*, for use in those expanding fisheries, led to their construction in German yards, with trawlers built and designed in the former USSR following later (Robinson, 2000).

Global expansion

Globally, in the past and present times, most fishing is structured at a very small scale – often with each vessel operating independently, while crews are paid by the share. Exploration for new grounds and new resources is necessarily limited, since crews go unpaid if nothing is found, while success swiftly draws competitors, who share the benefits but not the costs of exploration. Fishing captains usually seek to keep information from their rivals. The fisheries of the "Eastern Bloc" States, with their centrally planned economies, were markedly different. Future catches by commercial fleets could justify budgets for research and scouting ships, which sought out new resources. Information on catch rates was shared through fleets. The consequence was a massive increase in the pace of exploration for new resources, which in turn allowed fleets from the former USSR to emphasize fishing down high virgin biomasses, creating sequential depletions, rather than attempting sustained harvesting of established resources. Indeed, the very large fleets which were developed could likely not have been supported in any other way.

The needs of the former USSR was for catch volume, while their economic system allowed the exploitation of resources that would not have been viable for the fishing industry in market economies. With the support of subsidies, the fisheries of the former USSR grew rapidly: in 1950, their landings from all fisheries were 1.8 million tonnes – which almost doubled the 1.1 million tonnes landed by Imperial Russia in 1913 – though marine catches had replaced the former emphasis on the Caspian sea and inland waters. Landings then rose rapidly, reaching 3.5 million tonnes in 1960, 7.8 million tonnes in 1970 and 10.4 million tonnes in 1975, while *per capita* fish and seafood consumption nearly tripled between 1913 and 1976. Murmansk became the world's pre-eminent fishing port from 1952, replacing Hull and Grimsby (Helin, 1964; Solecki, 1979; Österblom and Folke, 2015).

Research and scouting vessels from the former USSR had explored the Grand Banks from 1954 (Marti, 1962). The first two of their new factory-freezer stern trawlers, *Pushkin* and *Sverdlovsk*, fished Flemish Cap for redfish in 1956 – and thus began by harvesting a long-lived, deep-living resource in the modern high seas. They did so more than a decade before overfishing began on the adjacent North American continental shelf and a half-century before such fishing became a particular concern for UNGA. Full-scale fleet operations began in 1957, when former USSR catches from the Grand Banks reached 69 000 tonnes (primarily redfish with a secondary catch of Atlantic cod). By the mid-1960s, the former USSR was sending more than 100 stern trawlers and more than 400 side trawlers (which off-loaded to "mothership" factories) to the northwest Atlantic. They had already fished down the redfish and increasingly turned to continental-shelf species (Rose, 2007). They also developed a new, and deeper, fishery for roundnose grenadier – its commercial-scale exploitation began in 1967, while catches peaked at 84 000 tonnes in 1971. The fishing began at depths of 600–800 m but by the 1990s regularly reached 1 500 m, with a few sets down to

2 000 m (Atkinson, 1995) – it was the first fishery to reach such depths, though it was conducted in an area now within the Canadian EEZ.

The success of the Cuban Revolution in 1959 led the new regime into tensions with the United States of America and, in the prevailing Cold War context, to closer ties with the former USSR. The Cuban people relied on imported seafood for much of their diet and, as part of the economic aid to its new ally, the former USSR funded the construction of a modern fishing port near Havana, in the period 1963–1965, and provided trawlers to work from it – all supported by loans to be repaid through services provided to former USSR fishing vessels. Besides its contribution to the Cuban economy, the facility was a forward-operating base that extended the practical operation of former USSR trawlers further from Murmansk and the Baltic ports (Anon., 1963, 1978). Preceded by scouting vessels from 1961, in 1966 the commercial fleet expanded its operations to take 56 000 tonnes of Argentine hake from the Patagonian Shelf. Argentina responded by extending its national jurisdiction to 200 nautical miles from shore. The former USSR fleet operated under Argentine licences in 1967 but took 680 000 tonnes, most of it hake. When Argentina raised the licence fees commensurate with such catches, the trawlers were withdrawn. They moved still further south and onto the marbled rockcod around South Georgia, taking 400 000 tonnes during the 1969/70 season, but only finding 100 000 tonnes the following year (Kock, 1992). That resource has not yet recovered. Thus, the potential generated by the nutritional needs of the people of the former USSR and technological developments (primarily in the United Kingdom of Great Britain and Northern Island) – both in turn shaped by the Second World War – was fulfilled by the consequences of revolution in Cuba, before leading to destructive overfishing in the sub-Antarctic.

While the former USSR's Northern and Baltic fishing fleets worked through the North and South Atlantic oceans, eventually reaching high seas grounds off the tip of the Antarctic Peninsula in 1978/79, the Black Sea fleet passed through the Suez Canal and steamed to the Indian Ocean sector of the sub-Antarctic. It took 300 000 tonnes, mostly of marbled rockcod, from the waters around Kerguelen during the 1970/71 and 1971/72 seasons (Koch, 1992). The Indian Ocean seamounts were explored en route but offered little with the technology of the time. Meanwhile, the former USSR's Far Eastern fleet pressed on beyond the Bering Sea grounds that it had fished in the 1950s, harvesting Sebastinid rockfishes as far south as the continental slope off Oregon by the mid-1960s (Ketchen, 1967). The fleets of the former USSR were not alone, however. The former USSR shared its technology with other "Eastern Bloc" states, often also sharing the services of its supply tankers and maintenance ships which made distant fleet operations possible. There were also similar factory-freezer stern trawlers from the Federal Republic of Germany, from Japan and eventually from the other major fishing nations of Western Europe and eastern Asia – though the fleets of the former USSR continued to dominate, at least numerically, until the late 1980s.

Outside of the North and South Atlantic, most of the fishing grounds opened up by the new stern trawler fleets now lie under national jurisdiction but the research and scouting ships also explored seamounts and other features in the modern high seas. Commercial fisheries briefly emerged on some of them, often fishing for alfonsino, but the only large fisheries developed after pelagic armourhead were discovered on the southern Emperor and northwestern Hawaiian seamount chains in 1967. Those were fished the following year, with combined former USSR and Japanese catches peaking at 178 000 tonnes in 1973, with an additional 31 000 tonnes of alfonsino. Thereafter, catches fell off very sharply.

The quarter of a century which followed the launch of *Fairtry*, (i.e. 1955–1980), thus saw a global expansion of distant-water bottom-fishing effort, which included the exploration of most of the potential high seas grounds, followed by development of most of the available resources. By 1980, the fishing down phase was largely over, even where resources had not been overexploited, and the great stern trawler fleets were left to survive on the remnants. The last potential grounds, along the ridges and rises of the South Pacific, were explored through the 1970s and into the 1980s (Clark *et al*., 2007).

They had already been faced with multiple major challenges. Factory-freezer trawling had been an energy-intensive mode of food production from its inception in the 1950s but that was the era of cheap oil. The 1973 "Oil Crisis" saw a quadrupling of the global price of crude oil and concomitant rises in the costs of diesel and bunker fuel. Meanwhile, developments in agriculture were lowering consumer prices for alternative forms of protein, notably chicken in developed, free-market economies. The "Eastern-Bloc" trawler fleets could be somewhat sheltered from those developments but the economic viability of the Western European fleets was tested. Moreover, from *Fairtry* on, factory-freezer trawlers had combined the capacity to take large catches with a necessity to do so, if they were to recoup their very high capital and operating costs. This necessity drove both the sequential fishing down of new resources and the over-exploitation of those potentially productive resources on continental shelves. Once there were no new resources to find, maintaining high catch rates became problematic, while depletion of coastal resources raised concerns for local fishermen and their governments. The latter (along with concerns over offshore petroleum resources, plus geopolitical considerations) led directly to the general international acceptance of extensions of coastal state jurisdiction to 200 nautical miles from baselines from 1976 onwards. For some years, the distant-water fleets continued to fish in various national zones, under license, but by 1980 their continued operations had largely finished.

Later developments

Orange roughy

In 1970, New Zealand had almost no fishing industry, only small coastal fisheries supplying local markets (Tull and Polacheck, 2001). The economy relied heavily on export of agriculture products to the United Kingdom, where they enjoyed favourable tariffs. That changed with the entry of the United Kingdom into the European Union in 1973. New Zealanders were confronted with major challenges, which led to a variety of entrepreneurial responses. As those changes unfolded, the international acceptance of extended national jurisdictions led, in 1978, to New Zealand declaring an EEZ which, by virtue of the distribution of its islands, is some 15 times larger than its national landmass and includes almost all of Zealandia, aside from the subtropical ridges in the northwest. As part of the overall economic re-orientation, offshore fishing was identified as one growth area, though the fishery potential was then almost unknown. New Zealanders then developed a new offshore fishing industry to take advantage of the resources they had acquired. Offshore fishing ships and their crews were the principal beneficiaries of the extended fisheries jurisdiction.

Japanese distant-water trawlers had previously developed fisheries for southern blue whiting, southern hake and hoki – the latter fished since 1969, typically at 200–800 m depth, with catches approaching 98 000 tonnes in 1977. The early expansion of the New Zealand fisheries focused on those same resources (Patchell, 1979, 1982). Exploration of the plateaux and ridges of sunken Zealandia inevitably involved fishing beyond normal continental shelf depths and, on the Chatham Rise, it encountered large aggregations, missed by the surveys and scouting of the distant-water fleets, of what had formerly been only a taxonomic curiosity: orange roughy. A directed fishery emerged within New Zealand's EEZ from 1979, with annual catches rising to about 50 000 tonnes by the mid-1980s (Clark, 1995; Branch, 2001). Once the industry learned to remove all subcutaneous fat from the fillets (which has a laxative effect), they proved ideal for the "white tablecloth" restaurant market, retaining their firm texture even after freezing and thawing, and lacking in any distinct flavour, allowing chefs to match them to any sauce. Landed prices were correspondingly high, while catch rates in the aggregations exceeded ten tonnes in as many minutes.

The Chatham Rise, with extensive areas of fishable bottom, was comparatively straightforward for fishermen to work. As the fishery expanded, however, locating and targeting those aggregations was increasingly demanding. By the mid-1980s, powerful echosounders suited to commercial operations were available, while the received echoes could be displayed on colour video screens – allowing much more subtle variations to be observed than with the old (and expensive) paper traces. Acoustic links between headline instrument packages and hull-mounted transceivers eliminated troublesome cable connections, allowing nets to be worked close to rough seabeds and hauled back once through an aggregation. High-precision navigation, once beyond radar range from land, continued to be a problem, as the roughy grounds were not covered by land-based electronic-navigation systems such as LORAN-C, while early satellite-navigation systems were poorly suited to fishing operations. Once the Global Positioning System (GPS), became fully functional in 1993, it became possible for a trawler captain to locate a roughy aggregation, survey the seabed around to determine a suitable path for his trawl, steam a few kilometres away to shoot the net, then return and place the gear on bottom, amidst the fish, with a spatial precision of roughly 10 metres. This allowed the specialized techniques for "hill fishing" – developed during the 1980s for trawling on previously inaccessible seamounts and other bathymetric features (Clark, 1995) – to be applied far from land.

The New Zealand orange roughy fisheries expanded beyond their EEZ from 1987, but the principal high seas expansion began on the Louisville Ridge in 1993–1994, followed by grounds off Namibia from 1995, on the South Tasman Rise from 1997 and on Indian Ocean seamounts from 1998. There was even a fishery off Scotland in the early 1990s, though in waters under European Union jurisdiction. Tragically, neither fishermen nor managers appear to have fully appreciated the consequences of the high longevity of orange roughy, nor the irrelevance of initial catch rates when predicting long-term sustainable yields. Even in Namibia, where managers aimed to learn from past mistakes in other waters, catches were not adequately constrained (Boyer *et al.*, 2001). The consequence has been a depletion of the roughy resources, apparently far beyond the fishing down that would necessarily have preceded sustained harvests of a long-term optimum yield. In the process, the roughy fisheries contributed more than most to the erroneous idea of an industry expanding across the oceans, destroying everything in the path of its trawls.

The deep fishing grounds of Zealandia, within New Zealand's EEZ, appear capable of supporting a sustained orange roughy fishery if managed with great care. The limited resources in the high seas may never have been capable of that. Rather, a brief "mining" effort lasted for about a decade, as an adjunct to the roughy fishing under national jurisdiction. Only a few hundred tonnes per year are now being landed from seamounts in the South Pacific and Indian Oceans.

Patagonian and Antarctic toothfish

Juvenile Patagonian toothfish had long been taken as bycatch by trawl fisheries off both coasts of South America and around the sub-Antarctic islands. However, it was only in the early 1980s that Chilean fishermen, with long experience of deep fishing in their national waters, developed techniques for catching adult toothfish by longlining at depths of several hundreds of metres. The fish proved to have similar attributes suitable for the "white-tablecloth" market as those of orange roughy and were equally valuable.

By the early 1990s the fishery had spread to the Patagonian Slope, where some of the grounds are in the high seas. Southwest Atlantic catches peaked at over 20 000 tonnes in 1995 (Gorini *et al.*, 2007). Meanwhile, longlining had already reached South Georgia during the 1985/86 season and spread eastwards through the sub-Antarctic islands, as well as the few fishable seamounts in the high seas of that latitudinal belt during the early 1990s. In each local area, reported catches peaked soon after fishing began and then declined. Reported annual catches from the Southern Ocean peaked at over 15 000 tonnes in 2000/01, though there was a very serious problem with illegal, unreported and unregulated (IUU) fishing, primarily during the 1990s in the EEZs around the islands. Estimated IUU catches reached 33 000 tonnes in 1996/97, but a suite of management measures has since reduced that problem.

From 1996/97, the legal fishery also began to target Antarctic toothfish (Kock, 2000), which lives further south, where the high seas reach the coastlines of both off-lying islands and the Antarctic continent itself. Thus, while annual catches of the species are only about 4 000 tonnes, it is the principal high seas toothfish. Most has been harvested in the Ross Sea, where the fishing grounds extend to the southernmost limit of the world's navigable waters. Most of the fishing is at depths between 1 000–1 600 m but gear is sometimes set as deep as 2 000 m. Annual catches remain stable by virtue of their strict management by CCAMLR.

Toothfish longlining is the only high seas bottom fishery that is still expanding its geographic reach. Since 2003 there has been some exploration for Patagonian toothfish on seamounts in the southernmost parts of the southeast Atlantic and the Indian Ocean, as well as in the Hjort Trench south of New Zealand. The fishery also expanded to seamounts on the Pacific-Antarctic Rise, north of the Ross Sea, in 2016. Meanwhile, CCAMLR is authorizing a gradual expansion of explorations for Antarctic toothfish around the Antarctic Continent.

Greenland halibut in Flemish Pass

When Namibia achieved independence in 1990, distant-water fishing states recognized its EEZ and were thus excluded from the hake resources of the Benguela Current ecosystem. The Spanish fleet, in particular, sought alternative high seas fishing opportunities. Spain conducted an experimental fishery for Greenland halibut ("turbot" to Canadian fishermen) in the Flemish Pass; the deep channel between Grand Bank and Flemish Cap (Durán Muñoz and Román Marcote, 2000). Many of the trawlers displaced from the southeast Atlantic started to fish in the Flemish Pass, working from 800 m downwards, reaching depths of 1 700 m in 1992, with some vessels being equipped to fish to 2 000 m. Estimated catches peaked at 75 000 tonnes in 1991, much of which was taken in the high seas. Disagreements over conservation limits led to the "Turbot War" between Canada and Spain in 1995 (Soroos, 1997), but the resolution of that disagreement contributed to the enhanced international management of the high seas fisheries.

The deep fishery for Greenland halibut continues in Flemish Pass but its catches have gradually declined. The resource was not found, or at least not fished, during explorations by the former USSR in the 1960s, which led to a fishery for roundnose grenadier over a very similar depth range and not far to the northwest.

Deep fishing around Rockall

Much of the development of the global high seas bottom fisheries has been led by fishermen working out of northern and western European ports, from Murmansk to Vigo. Most of that has, however, required fishermen to steam to very distant waters: deep-sea bottom-fishing grounds are limited in the high seas of the northeast Atlantic. Aside from the "loophole" in the Barents Sea (entirely surrounded by the EEZs of Norway and Russia), there are portions of the Mid-Atlantic Ridge between Iceland and the Azores that can be fished, a few isolated seamounts, and the Rockall Plateau – the latter an isolated fragment of continent that is almost entirely submerged. The shoal water of the Plateau has been fished for at least two centuries (Blacker, 1982) but it has not proven to be highly productive. Conversely, the European continental margin and the oceanic ridges within modern EEZs are highly productive and supported the early development of deep trawling, initially for European hake soon after 1900, and for redfish later especially in the 1930s. One area of particular note is the Rockall Trough, a tongue of deep water north of Ireland and west of Scotland, delimited on its northwest side by the Rockall Plateau.

During the 1990s, and with the advantage of proximity to European markets and ports, a number of new, deep fisheries emerged in the northeast Atlantic. German, and later French trawlers, had developed a fishery for blue ling in the 1970s, while United Kingdom fishermen developed a fishery for deep-living monkfish. In the late 1980s, the French fleet began to land roundnose grenadier, which had formerly been discarded, though targeted in the 1970s by vessels from the former USSR. Orange roughy were found in the 1990s by French trawlers at depths below 1 000 m – both French initiatives being seen at the time as responses to the depletion of shallow-dwelling gadoid resources. Black scabbardfish and deepwater "siki sharks" were also landed though the fishery for the latter has ended (Charuau *et al*., 1995; Large *et al*., 2003, ICES, 2015a, 2015b). Further orange roughy were found and developed by Irish vessels. A Spanish trawler fleet began work in the area in 1996, alongside longliners and gillnetters. Some of those fisheries passed into the high seas in 1997 when the United Kingdom acknowledged Rockall as a rock incapable of sustaining human life and hence ineligible, under UNCLOS, as a basis for claiming an EEZ. The northeast Atlantic catch of the above species was 26 500 tonnes in 2004, 73 500 tonnes the following year (Bensch *et al*., 2009), 202 000 tonnes in 2011 and 173 000 tonnes in 2012 (FAO, 2019). However, almost all of it is taken along the continental margin, including on the southeastern side of the Rockall Trough, and so under national (or European Union) jurisdiction. Catches from the limited fishing area in the high seas have only been tabulated separately since 2012 but amounted to just 8 500 tonnes in 2013 – most of it roundnose and roughhead grenadier, redfish or Baird's slickhead.

CLOSURES AND RESOURCE RECOVERY

Severe depletions of many groundfish resources in the northwest Atlantic and the rockcod resources of the Southern Ocean reached a nadir during the 1990s. Other high seas stocks were heavily exploited in the 1960s and 1970s and yielded exceptionally high catches for short periods of time, but these are less well documented. Examples include: orange roughy in the South Pacific, southeast Atlantic, and Indian Ocean, and to a lesser extent the northeast Atlantic; Pacific Armourhead in the North Pacific; various rockcod species in the Southern Ocean; and possibly alfonsino in the northwest Atlantic (details provided in the respective regional chapters). These examples resulted in stricter management controls, sometimes leading to the fishery's closure for varying lengths of time. On occasion stocks have recovered to commercially fishable levels, in which cases the closures have usually been lifted, while other stocks have seen no recovery and closures thus remain in place. Recovery is typically the result of a combination of reduced fishing mortality in target and bycatch fisheries, and strong recruitment resulting from favourable environmental conditions.

Fishery closures, in the sense that the TAC for targeted fisheries is reduced to zero and bycatch is kept to a minimum, are typically a last resort for a fishery management body. Closures cause additional difficulties to both the industry and managers; markets are lost and information on stock status is hard to monitor. In most cases, the preferred option is to reduce the TAC early enough to allow for stock recovery prior to stocks becoming so low that their recruitment is impaired. Nevertheless, closures have been necessary in some areas, though typically they are more common in those areas that have more established management practices (Table 3.5).

TABLE 3.5

Demersal fisheries under moratorium by RFMOs showing the years closed and the applicable TACs (tonnes) in 2016 and 2019

Region	Closed	Opened	TAC 2016	TAC 2019	Most recent status
Northwest Atlantic (NAFO)					
Atlantic cod 3L	1994	continues	0	0	B very low
Atlantic cod 3NO	1994	continues	0	0	B<Blim; F<Flim
Atlantic cod 3M	1999	2010	13 931	17 500	B>Blim; F<Flim
American plaice 3LNO	1995	continues	0	0	B<Blim; F (bycatches) delaying recovery
American plaice 3M	1995	continues	0	0	?
yellowtail flounder 3LNO	1994	1998	17 000	17 000	B>Bmsy; F<Flim
witch flounder 3L	2004	continues	0		?
witch flounder 3NO	1995	2015	2 172	1 175	B2018<Bmsy; F<Fmsy
redfish in 3LN	1998	2010	10 400	18 100	HCR in place since 2016
northern shrimp 3M	2011	continues	0	0	B<Blim; F=0 (ndf)
northern shrimp 3LNO	2015	continues	0	0	B<Blim; F=0 (ndf)
Northeast Atlantic (NEAFC)					
spurdog	2010	continues	No TAC	0 (ndf)	B low; F low
deep-sea sharks, rays & chimaeras	2017	continues	No TAC	0 (ndf)	?
orange roughy SA5 6 7	2007 (Jan–Jun) 2008 2010 2011 2013 2014	2016	0	No TAC agreed	B very low; F above advice
Southern Ocean (CCAMLR)					
marbled rockcod area 48	1985/86	continues	0	0	32:02
other rockcod spp various areas	1990	continues	0	0	32:02
toothfish various area	1990	continues	Various	Various	Where known, B and F acceptable
North Pacific (NPFC)					
C-H Seamount (North Pacific armourhead)	(2009) 2016	continues	0	0	B low F low
Southeast Atlantic (SEAFO)					
orange roughy Div. B1	2010	continues	0 TAC (4 tonnes bycatch)	0 TAC (4 tonnes bycatch)	B low F low

Estimates of the most recent status are provided using information provided by RFMO Scientific Committees. The status is often difficult to assess but is given here for a snapshot in time using the most recent assessment (usually 2017 or 2018).
Green is satisfactory, yellow is intermediate, and red is unsatisfactory. In many cases, and for various reasons, recovery has been slow to non-existent even when fishing pressure has been very low. Assignment to these colour categories is often subjective and not always provided by RFMOs.

The high seas of the northwest Atlantic have seen the greatest number of closures; they began in 1994, and 11 stocks have closed since NAFO came into force in 1979. Of these, only four have recovered sufficiently to be re-opened, with Atlantic cod in Div. 3M, yellowtail flounder in Div. 3LNO and redfish in Div. 3LN, each having TACs of over 17 000 tonnes in 2019. The other, witch flounder in Div. 3NO was opened in 2015 and still has a very precautionary TAC owing to recent poor recruitment and concerns that the stock is not recovering well. The other stocks are showing little signs of recovery, hampered as they are by poor recruitment resulting largely from unfavourable environmental conditions, and bycatch in multispecies fisheries.

In the furthest reaches of the northeast Atlantic region, a new resource of the newly colonized snow crab emerged in the high seas “loophole” in the Barents Sea in 2012, presumably driven by environmental change. As a sedentary resource on an extended continental shelf, it is likely that the management will fall under the jurisdiction of Norway and the Russian Federation who exploit it. This international fishery emerged in the high seas enclave and by 2016 catches had risen to over 4 600 tonnes (inclusive of shell weight).

DEEP FISHERIES IN THE MEDITERRANEAN SEA

The origins of fishing in the Mediterranean lie far back in time. The proximity of the high seas to some coasts suggests that deep-sea fishing could have historically extended beyond the limits of modern national jurisdictions. Deep fishing, however, began only recently and is still expanding. During the 1930s, shrimp-trawl fishermen working the Ligurian Sea (between Corsica and the Italian mainland) expanded their operations beyond the 400 m isobath, where they took “red shrimp” – a combination of giant red shrimp and blue and red shrimp. Similar fishing emerged off the Catalan coast of Spain and around the Balearic Islands during the 1940s, with fishing depths reaching 700 m in those areas. During the 1980s there was further expansion down to 1 000 m (Sardà *et al.*, 2004a). Other deep shrimp fisheries emerged subsequently around the Mediterranean, as much by local development as by spreading from the western basin. Fishing for “red shrimp” on the now predominant grounds in the Strait of Sicily only began in the 1960s; after 2000 it spread to the Levantine Sea and is still in a developmental phase there. Small-scale, nearshore deep fishing may have gone unrecorded – potentially for centuries – but larger-scale finfish fisheries below 400 m depth did not appear until the 1990s.

Whether the growth of deep fishing in the Mediterranean was strongly linked to the availability of resources in shallower water is unclear. Many shallow-dwelling resources were heavily fished, and hence depleted, before deep fishing began. Opportunities for further expansion in shallow waters were therefore restricted, while rich resources could be found at greater depth. However, deep trawling would not have been a viable option much before it actually emerged in the 1930s, as it requires fully powered trawlers. Without the abundant resources needed to support the larger steam trawlers used in the North Sea, exploitation had to await the development of diesel engines in sizes suited to smaller vessels, and then the acquisition of sufficient capital for fishermen to purchase motorized trawlers. The political and economic histories of that development have yet to be studied, but it may be significant that the deep shrimp fisheries appeared in Italy and Spain during the early years of the Mussolini and Franco regimes, when each promoted modernization of their national economies. Why those fisheries have been so slow in spreading eastwards is unclear.

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4. High seas bottom fisheries management

INTERNATIONAL INSTRUMENTS FOR THE MANAGEMENT OF BOTTOM FISHERIES IN THE HIGH SEAS

UNGA instruments

The United Nations General Assembly (UNGA), adopted the 1982 Convention on the Law of the Sea (UNCLOS, 1982) and the 1995 UN Fish Stocks Agreement (UNFSA, 1995) for, the management of fisheries in the high seas, among other things. This declares that the management of fisheries in the high seas – i.e. beyond territorial waters and Economic Exclusion Zones (EEZs) – is the responsibility of the flag states undertaking the fishing, either individually or through Regional Fisheries Management Organizations/Arrangements (RFMO/As). The management of fisheries in the high seas in regions with RFMO/As is generally undertaken cooperatively by RFMO/A member states. However, in some cases, states or economic entities such as the European Union may have their own, more restrictive measures that apply to their flagged vessels. Fisheries management in high seas that do not have an RFMO/A, is the responsibility of the flagged state of the vessels fishing in that region. These duties and obligations are primarily set out in Articles 116–119 of UNCLOS. Only those states which are members of such an organization or participants in such an arrangement, or which agree to apply the conservation and management measures established by such an organization or arrangement, shall have access to the fishery resources to which those measures apply, as set out in UNFSA Article 8.4. UNCLOS and UNFSA entered into force in 1994 and 2001, respectively. Annual UNGA resolutions are adopted and serve to support, strengthen and provide current focus to UNCLOS and UNFSA. Whereas UNCLOS and UNFSA are binding for their signatories, the resolutions are applied voluntarily.

UNCLOS gives states the right to fish in the high seas subject to various provisions relating to the need to determine allowable catches, and establish conservation measures to ensure that fisheries are sustainable and that populations of associated or dependent species are maintained (UNCLOS, Article 119). This is elaborated upon further in UNFSA.

FAO instruments

The Food and Agriculture Organization of the United Nations (FAO) has also adopted both binding and voluntary instruments that support the implementation of specific aspects of UNCLOS and UNFSA. The FAO Compliance Agreement (FAO, 1995a) entered into force in 2003, and aims to improve the regulation of fishing vessels on the high seas by strengthening flag state responsibility. Parties to the Agreement must maintain an authorisation and recording system for high seas fishing vessels and ensure these vessels do not undermine international conservation and management measures. Provisions exist for international cooperation and exchange of information in implementing the Compliance Agreement, particularly through FAO. The 2009 FAO Port State Measures Agreement (PSMA) entered in to force in 2016 to deter illegal, unreported and unregulated (IUU) fishing by preventing vessels engaged in IUU fishing from using certain ports to land their catches (FAO, 2010). The PSMA reduces the incentive of such vessels to continue to operate by blocking fishery products derived from IUU fishing from reaching many of the more lucrative national and international markets. Both of these two measures are binding for the parties to each agreement.

The 1995 FAO Code of Conduct for Responsible Fisheries (FAO, 1995b), and the supporting technical guidelines and international plans of action (IPOAs) (FAO, 2019a,b), are non-binding instruments and are applied voluntarily by states. Their function is to promote responsible fisheries by providing guidance on good practice for developing ecological, social and economic elements in fisheries management. They provide a reference framework in the formulation of policies and other legal and institutional frameworks and instruments, in order to ensure sustainable fishing and production of aquatic living resources in harmony with the environment.

Other international instruments

The only other international instrument that has a bearing on fishing, is the Convention on Biodiversity (CBD, 1993) that arose from the 1992 Rio Earth Summit. The Convention entered into force in 1993 and its principal impacts on the management of fisheries are to:

> *Integrate consideration of the conservation and sustainable use of biological resources into national decision-making [and] Adopt measures relating to the use of biological resources to avoid or minimize adverse impacts on biological diversity.*
>
> **(Article 10a, b)**

The CBD has changed the way in which states and RFMO/As consider fisheries management, largely moving away from the typical single-species resource assessments of the 1960s and 1970s, to a multispecies ecosystem approach to fisheries management – that considers both the target resource and biodiversity conservation – which emerged in the 2000s.

Global development goals

The 2000–2015 Millennium Development Goals (MDGs) and the 2016–2020 Sustainable Development Goals (SDGs) both set targets for reducing overfishing and biodiversity loss, and for restoring fish stocks to levels that can provide the maximum sustainable yield. In order to achieve this, management bodies have introduced restrictive measures by closing some fisheries to rebuild stocks and by closing areas to protect certain vulnerable bycatch species. These types of measures are not new to fisheries management – for example, the North Sea herring fishery was closed in 1978 to rebuild its stock – but they are now being increasingly applied as a precautionary measure to prevent stock collapse.

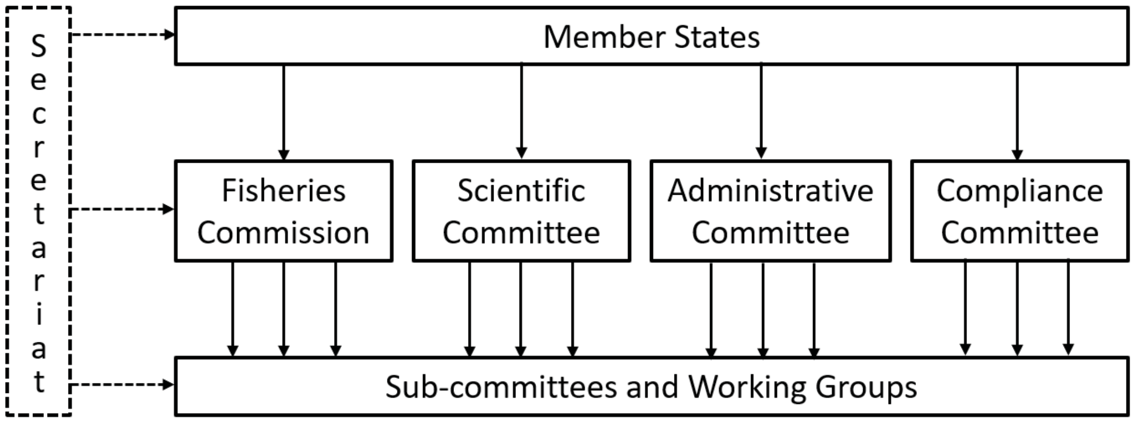
Multilateral instruments

States adopt multi-lateral instruments in the form of conventions, treaties or agreements, which allow for a specified degree of control over the activities that occur in international waters. These agreements can be made within the 1949 FAO Constitution (FAO, 1949) (Article VI and Article XIV bodies), or they can be made outside of the FAO framework. Such regional agreements to manage fisheries may be binding or non-binding on their Members and cooperating states. This was codified in UNCLOS when it entered into force in 1994, which gave a legal basis to such an arrangement. Multilateral agreements existed prior to this but had no higher legal basis in international law. This impeded the application of the obligations specified in the multilateral agreements, especially when negotiations among the Member States failed to reach consensus on important issues. When dealing with bottom fisheries, these agreements normally cover a specific region or area of the ocean in the high seas (or Areas Beyond National Jurisdiction (ABNJ)), that may or may not include EEZs and territorial waters. However, the latter areas are always under the jurisdiction of the appropriate state, though cooperative arrangements are often made to manage straddling and highly migratory stocks that occur on both sides of the EEZ–high seas boundary (as required by the UNFSA).

The aforementioned multilateral agreements serve as a forum for Member States to coordinate their fishing activities, and it is the Member States that control the organizations established to implement the agreements. Decisions are made and adopted through different processes that range from voting, to agreement on the basis of consensus, or some similar agreed method. The structure of most regional fisheries bodies (RFBs) is broadly similar and includes a decision-making committee often called a commission, in addition to a scientific advisory committee, an administrative committee to manage the overall operations and affairs of the organization, and often a compliance committee for managing adopted measures. These committees are usually supported by sub-committees and working groups that undertake much of the technical work. These committees and working groups are made up of representatives from the Member States. The only legal entity is the Secretariat which, based at a permanent headquarters, manages the day-to-day running of the RFB and supports the committees to undertake, implement, and monitor the duties of the organization as required by Member States. Secretariat employees do not represent Member States. The details of the structures in the individual RFBs vary from the general schematic outline shown in Figure 4.1.

FIGURE 4.1

General schematic outline of the structure of regional fisheries bodies. A Compliance Committee is more evident in regional fisheries management organizations (RFMOs) that adopt regulations for management purposes



Regional fisheries bodies – advisory and regulatory

There are two broad categories of RFBs. Those that act in an advisory capacity to Member States, and those that act in a regulatory capacity; both are established by a multilateral agreement. Advisory bodies tend to be fora for the collection and analysis of fisheries information such as vessel registries, catch and effort data, and biological data relevant to the fisheries. They often provide assessments on the state of the fished stocks and provide advice to Member States on measures necessary to manage the region's fisheries. However, there is rarely coordination among states in the development and adoption of their national measures.

The RFMO/As are governed by an agreement that requires them to develop and adopt fisheries management measures; these are binding for Member States. The measures are to be based on the best scientific advice and should both conserve fish stocks at levels that provide a maximum sustainable yield and protect the environment these fish species inhabit. They are usually provisions that allow Member States to object to a measure and thus not be bound by it. In general, RFMOs are mandated only to manage fisheries, though in recent times this has included the management of impacts the fisheries may have on the ecosystem where fishing occurs. The most publicized is the protection of Vulnerable Marine Ecosystems from impacts caused by vessels fishing with gears that contact the sea floor, and this typically involves the closure of certain areas to bottom fishing. However, there are many more similar regulations that protect the spawning and breeding of exploited fish and address the impacts that fisheries can have on seabirds, mammals, turtles, etc.

A map and a list of the RFBs (RFMO/As, CCAMLR and advisory bodies) with mandates for deep-sea fisheries are provided in Figure 1.1 and Table 4.1 respectively.

Regional bodies – with broader regulatory remits that include fisheries

The convention for the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), the regional body that manages fisheries in the Southern Ocean around Antarctica, has a broader remit than the RFBs. CCAMLR is responsible for managing all biological components of the marine ecosystem within its area, though in practice the management of fisheries still comprises most of their work. However, their fisheries management is set within an ecological and multispecies framework to a greater extent than seen in other regions.

Regional fisheries bodies – interim arrangements

The establishment of an RFB is a complex process that requires several years of negotiations to develop and adopt the agreement text, in addition to a further period for the agreement to be ratified by Member States prior to its entry in to force. The interim RFB does not have any formal mandates or duties during this interim period. Nevertheless, interim RFBs often function in a manner consistent with their future function and tend to have a working commission and scientific committee for most practical purposes. This often includes the adoption of some "basic" interim measures that usually attempt to maintain the fishery at a current status quo to avoid increases in catch and effort. However, although these measures are applied voluntarily, they are often effective and help define and develop the future work of the RFB once its agreement enters into force.

High seas areas without RFMO coverage

There are still areas of the high seas with no RFMO/A that has competence over bottom fisheries. The gaps are, from north to south:

- The central basin of the Arctic Ocean (other than the segment between 42° West and 51° East, which falls within the NEAFC Convention Area). There is no bottom fishing in that area, nor is there likely to be in the foreseeable future, but multilateral discussions concerning future fisheries management nevertheless commenced in 2010.
- A high seas enclave in the Bering Sea: the "Donut Hole". There is very little fishable bottom within the enclave, though some continental-slope trawling may occur. The area is notable for a walleye pollock fishery that operated from the late 1980s until 1992. However, that fishery was for a fully pelagic population of a traditionally demersal species. Should the population recover from its depleted state, any new fishery would be subject to the Convention on the Conservation and Management of Pollock Resources in the Central Bering Sea, which entered into force in 1995. The convention does not apply to fisheries for other species.
- A high seas enclave in the Sea of Okhotsk: the "Peanut Hole". Under Article 16 of the UN Fish Stocks Agreement, the Russian Federation has exerted effective control over the enclave, closing fisheries for walleye pollock in the area, while

TABLE 4.1

Regional fisheries bodies with competence over bottom fisheries in the high seas

Region	Body	Acronym	Type	Established (concluded)	Convention (and amendments[1])	Area of competence	Regulatory area
Northeast Atlantic Ocean	North East Atlantic Fisheries Commission	NEAFC	RFMO	1959 (1979) 1980	1959 1982 (2004, 2006)	Marine waters[3] – northeast Atlantic	High seas
Northwest Atlantic Ocean	Northwest Atlantic Fisheries Organization	NAFO	RFMO	1979	1979 (1980, 1987, 1996, 2007)	Marine waters[3] – northwest Atlantic	High seas – northwest Atlantic
	International Commission for the Northwest Atlantic Fisheries	ICNAF	RFMO	1949 (1979)	1949	Marine waters[3] outside of territorial waters –– northwest Atlantic	Marine waters* outside of territorial waters – northwest Atlantic
Eastern central Atlantic Ocean	Fishery Committee for the Eastern Central Atlantic	CECAF	RFB (FAO Art. VI)	1967	1967 (1992, 2003)	Marine waters[3] – east central Atlantic	None
Western central Atlantic Ocean	Western Central Atlantic Fishery Commission	WECAFC	RFB (FAO Art. VI)	1973	1973 (1978, 2006)	Marine waters – western central Atlantic[3]	None
Southeast Atlantic Ocean	South East Atlantic Fisheries Organisation	SEAFO	RFMO	2003	2001	High seas – southeast Atlantic	High seas – southeast Atlantic
Southwest Atlantic Ocean	None	–	–	–	–	–	–
Mediterranean and Black Seas	General Fisheries Commission for the Mediterranean	GFCM	RFMO (FAO Art. XIV)	1949	1949 (1963, 1976, 1997, 2014)	Marine waters of the Mediterranean Sea and Black Sea	Marine waters of the Mediterranean Sea and Black Sea
North Pacific Ocean	North Pacific Fisheries Commission	NPFC[2]	RFMO	2015	2012	High seas – North Pacific	High seas – North Pacific
South Pacific Ocean	South Pacific Regional Fisheries Management Organisation	SPRFMO[2]	RFMO	2012	2009	High seas – South Pacific	High seas – South Pacific
Indian Ocean	Southern Indian Ocean Fisheries Agreement	SIOFA	RFMA	2012	2006	High seas – Southern Indian Ocean	High seas – Southern Indian Ocean
Antarctic and Southern Oceans	Commission for the Conservation of Antarctic Marine Living Resources	CCAMLR	Regional body	1982	1980	Marine waters – Southern Ocean	Marine waters – Southern Ocean

[1] Amendments adopted by the organization, but not necessarily in force.
[2] NPFC (2006–2015) and SPRFMO (2006–2012) existed in an interim phase prior to the conventions entering into force and met regularly in an advisory capacity to Member states.
[3] "Marine waters" represents an area of the ocean bounded by lines of latitude and longitude to the coastlines. The high seas may have been separately identified after UNCLOS entered into force. See individual conventions and agreements for exact details and wording.

granting licences for fishing in more productive waters within the Russian EEZ to trawlers under other flags.

- There are extensive, though sub-divided, areas of high seas in the tropical zone between the Convention Areas of the North Pacific Fisheries Commission (NPFC) and the South Pacific Regional Fisheries Management Organization (SPRFMO). There is little to no bottom fishing in those waters and no major fishery is likely to develop, though some minor activity remains possible.
- A considerable extent of the northern Indian Ocean, including the entire Arabian Sea and Bay of Bengal, lies outside the Area of Application of the Southern Indian Ocean Fisheries Agreement (SIOFA). As with the tropical Pacific areas, no major fishery is likely to develop in those latitudes, though minor activity is possible.
- No multilateral arrangement for the management of the high seas bottom fisheries of the southwest Atlantic has yet emerged. This area, though small in size, supports large fisheries, which generate about 40 percent of the global catch.

MANAGEMENT MEASURES

RFMO/As have introduced suites of measures for deep-sea fisheries, each adapted to regional requirements and fisheries, that incorporate many of the conventional tools of marine fisheries management. There is typically a chronological order to the types of measures adopted, though this is more variable for deep-sea fisheries, owing to difficulties in collecting adequate information to underpin measures by solid scientific advice. Furthermore, the nature of fisheries has changed since the 1960s, when fisheries were developed and promoted mainly on the premise of providing food for the world's growing population. In more recent times, having seen many productive fisheries suffer from over-exploitation and reduced yields, the development of new fisheries should only be allowed to expand only at a rate consistent with the information gained to manage that fishery sustainably. However, and as explained in some of the subsequent chapters, some established fisheries still suffer from excessive exploitation rates, and some new fisheries still suffer from uncontrolled expansion.

The first sets of measures are usually technical in nature and control aspects such as minimum fish landing sizes and minimum gear mesh sizes. Vessel registries and licensing schemes, together with some degree of limited entry or effort control, are also usually introduced early in the suite of measures. Thereafter, and typically following concerns of over-fishing, TACs and quotas are introduced, but in the knowledge that the implementation of this requires considerable information on catch and effort, as well as on monitoring and control. Hence, measures adopted around this time aim to improve reporting and apply MCS schemes. Some fisheries have been closed following stock collapses in order to reduce fishing pressure and promote recovery to levels that can once again support a sustainable fishery (see Table 3.5). After this comes the application of temporal and spatial closures to protect some aspect of the target stocks' life history or to protect associated species, which has become increasingly common in recent times. Bycatch rules may be put in place around this time to protect some especially vulnerable groups such as seabirds or species from closed fisheries; move-on rules and even fishery closures may also be associated with this. Most recently, and typically only applied to bottom fisheries, are sets of measures designed to ensure that new fisheries are controlled to avoid excessive effort and early stock collapse, which is a common occurrence with new fisheries.

The above overview varies according to region and species, and while it is a rather crude simplification it provides an idea as to how measures develop and evolve through time. Some examples of when these types of measures were first used by RFMO/As in various regions – though not necessarily for bottom fisheries – are shown in Table 4.2.

A major development in the last decade has been the response to UNGA's concerns about impacts caused by deep-sea fisheries, particularly those on vulnerable marine ecosystems from fishing using bottom contact gears. This was driven by UNGA Res. 61/105 and 64/68,

TABLE 4.2

Examples of measures adopted by regional fisheries bodies to manage fisheries and when they were first applied by those established before 1990

Criterion and measures	Explanation	First example (with source)[1]
Minimum mesh sizes	Restrictions placed on mesh size in fishing gears	NAFO: 130 mm finfish, 60 mm squid. CEM 1981 CCAMLR: 1985 (2/III) GFCM: 40 mm sq. mesh. CM 2009-2
Minimum fish landing sizes	Restrictions place on the size of fish landed	NAFO: 41 cm cod, etc. CEM 1994
TACs and quotas	TACs and quotas.	NAFO: TAC and quotas for capelin and squid (CEM 1979) CCAMLR: TAC for *Patagonotothen brevicauda guntheri* 1988 (3/IV)
Catch recording/reporting		NAFO: Logbook for fish on board CEM 1981 Part I CCAMLR: Catch reporting for *Champsocephalus gunnari* 1987 (9/VI)
Bycatch limits	Limits set on catch of non-target species.	NAFO: Groundfish in shrimp trawls (CEM 1994) CCAMLR: Bycatch of *Notothenia rossii* to be kept to a minimum in SA48.3 1985 (CM 3/IV)
Closed areas, closed seasons	Specific areas with fishing restrictions	NAFO: In force by 2000 CCAMLR: 1985 Fishing ban around South Georgia (1/III). 1989 closed season on *Champsocephalus gunnari* (15/VIII) GFCM: 1000 m ban (CM 2005-1)
Bans on particular major gear types (otter trawls, gillnets or trammels	Bans on certain gears over large areas	CCAMLR: 2006 Gill-netting (CM 22-04), bottom trawling (CM 22-05)
Closures of specified fisheries	Fisheries closed to protect stock or other species	NAFO: Cod and yellowtail. CEM 1994 CCAMLR: Closure on *Notothenia rossii* in SA 48.3 1985 (CM 3/IV)
Limits on fishing effort or fishing capacity	Restrictions on numbers of vessels fishing or amount of fishing	NAFO: CEM 1996 GFCM: 2010-2
Monitoring, Control and Surveillance (MCS)	Strict scheme in place	NAFO: CEM 1979 CCAMLR: 2002 IUU list (CM 10-06) GFCM: CM 2010-3
Vessel registration	Record of vessels permitted to fish	NAFO: CEM 1982 CCAMLR: 1993 CM 65/XII GFCM: 2010-2
Restrictions placed on new fisheries	New fisheries only permitted to develop at controlled rates	NAFO: CEM 2010 CCAMLR: 1991 CM31/X

[1] NEAFC only list measures from 2000 on their website. It is likely that similar measures were in place at similar times to NAFO. RFMOs in other regions were established later. Sources for measures are provided on the RFMO websites.

and the subsequently developed FAO Deep-sea Fisheries Guidelines. This has resulted in a more or less consistent set of measures that regulate and control deep-sea fisheries in a more general sense. Each RFMO/A has adopted, or is in the process of adopting, closures of identified areas containing VME, in addition to some form of protocol controlling responses to encounters with VME outside those closures, and limits on the "footprints" of the fisheries. In most regions the latter has involved mapping past fishing activity, defining an existing "footprint" and establishing a protocol for exploratory fishing outside the existing spatial limits. In the process, the dynamics of initiating fishing in the high seas has been reversed: where these were generally open to fishing beforehand, except were limited by conservation measures, the majority of each region is now effectively closed until proponents develop detailed fishing plans and accompanying impact assessments. To date, the limited prospects for new high seas bottom fisheries seem not to have justified the expense of developing the required plans and assessments. The fisheries are therefore effectively constrained to their established areas and resources.

In all cases, the RFMO/As' adopted conservation and management measures can only be applied to individual fishing vessels through regulations or other requirements imposed by their flag states. Most RFMO/As have procedures for routinely checking and reporting whether their Member States are complying with multilateral decisions – with a further complication for some European vessels, insofar as their RFMO/A member is typically the European Union, not the individual flag state – though it is the latter which directly impose controls on the vessels. Where there is no RFMO/A with competence over bottom fisheries, which primarily means the high seas portion of the Patagonian Shelf, flag state management is pre-eminent – albeit with important contributions by the European Union, whose vessels dominate the fisheries in that area. Despite the importance of national management, it is not possible for this review to examine the numerous measures imposed by individual flag states.

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5. Northeast Atlantic Ocean

FAO Major Fishing Area 27, excluding portions in the Arctic Ocean

SUMMARY

The northeast Atlantic has a long history of highly productive fisheries, especially over the wide continental shelf areas that lie largely within EEZs. The high seas demersal resources are relatively small, especially when compared to those in the EEZs. There are four high seas areas in the northeast Atlantic, though only the "Loophole" in the Barents Sea and the northeast Atlantic Oceanic area south of the Greenland–Scotland ridges support demersal fisheries. The area in the Arctic is frozen and the "Banana Hole" area in the Norwegian Sea is believed to be too deep and cold to support bottom fisheries.

Bottom fisheries in the high seas of the northeast Atlantic Oceanic area underwent rapid expansion in the 1970s, reflecting a trend observed in many regions of the World's oceans at that time. However, the initial high catches quickly diminished and stock biomasses declined, as many of the aggregating species were less productive than first assumed. Nevertheless, exploitation rates remained relatively high through the 1990s, leaving many stocks in a depleted state as a result of overfishing. Most of these demersal resources are fished at depths of 200–1 200 m, but there is also a relatively shallow regular fishery for haddock and ling in the high seas, primarily to the west of the British Isles.

The finfish fisheries of the "Loophole" in the Barents Sea mainly harvest gadoids and small quantities of Greenland halibut, but these landings are a tiny fraction of a percent of their neighbouring EEZ fisheries. Shellfish fisheries are the most important fisheries in the "Loophole", comprising of northern shrimp and the recently colonised snow crab.

The North East Atlantic Fisheries Commission (NEAFC) is responsible for the management of the fisheries in the high seas of the northeast Atlantic, where these are part of the NEAFC regulatory area, drawing on scientific advice provided by International Council for the Exploration of the Sea (ICES). In practice, this applies more to the oceanic areas of the northeast Atlantic, as the "Loophole" fisheries are more actively managed by JointFish and coastal States. The principal NEAFC fisheries are for pelagic species such as redfish, mackerel, herring and blue whiting; these species are not discussed in this report, but in 2016 they accounted for over 95 percent of the entire catch of NEAFC-controlled species in their regulatory area, with a combined catch of 415 911 tonnes. As a comparison, the total fish catch in Area 27 (EEZs and high seas) amounted to 8 072 704 tonnes in 2016, of which 33 433 tonnes were tuna and tuna-like species managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT) in the high seas.

As ICES began providing management advice on the pertinent fisheries inside and outside EEZs in the mid-1990s awareness of the need to regulate deep-sea fisheries increased, but science advisors faced the challenge that most of the fisheries were young and data-poor. Interest in the bottom fisheries – and particularly the minor fisheries with lower catches often occurring on deeper slopes, ridges and seamounts – gained additional momentum around 2005, when the UNGA Resolutions on sustainable deep-sea fisheries and the protection of vulnerable marine ecosystems were adopted by the UNGA. The development of management measures was challenging, since most

of the high seas deep-sea fisheries and bottom fisheries for shelf species were small and poorly documented. Although ICES had provided precautionary advice statements since the early 2000s, improvements in data collection, accumulation of time-series, and new techniques meant that quantitative advice on many of the deep-sea stocks could only be provided from 2012 onwards.

The bottom fisheries along the Mid-Atlantic Ridge (MAR) occur almost exclusively in the high seas, particularly orange roughy and roundnose and roughhead grenadier. The latter are also important in high seas catches around the deeper eastern parts of the Rockall and Hatton Banks (a substantial part of the grenadier catch is taken by midwater trawls, but these are included here among bottom fisheries catches). Perhaps the only other species with a high proportion caught in the high seas is snow crab in the "Loophole" of the Barents Sea, which is regarded as a sedentary species. The other fisheries are relatively minor extensions of more substantial fisheries for EEZ shelf stocks. Some of these, for example the fishery for northern shrimp in the "Loophole", have significant high seas catches, but remain small when compared to catches within the EEZs. Estimates of high seas catches have been compiled for only some of the species and stocks, and they tend to be more complete from 2012 (ICES WGCRAB, 2016; ICES AFWG, 2018; ICES WGDEEP, 2018; NEAFC, 2019). The estimated total catch in the NEAFC regulatory area in 2016 was 21 544 tonnes, making up 4.5 percent of the total catch of NEAFC-regulated species. Of this, 13 726 tonnes was snow crab and northern shrimp from the "Loophole" in the Barents Sea (Table 5.1).

GEOGRAPHIC DESCRIPTION

The high seas of the northeast Atlantic comprise three subareas and extend over a total area of 13 007 000 km^2 (Figure 5.1; Table 5.2): the single extensive area in the northeast Atlantic Ocean and the two smaller enclaves – the "Banana Hole" in the Norwegian Sea and the "Loophole" in the Barents Sea. The area excludes the Arctic Ocean, and the Mediterranean and Black Seas.

The "Loophole" is the only part of the high seas of the northeast Atlantic where the wide continental shelves extend into the high seas. This enclave is entirely at continental-shelf depths. The Central Bank is shallower than 200 m, though deepens in the southern corner to form a basin deeper than 300 m (Figure 5.2a).

The "Banana Hole" forms another high seas enclave in the Norwegian Sea. Its water depths are mostly greater than 2 000 m. The shallowest part is on the edge of the Vøring Plateau, which extends into the southeast corner with a minimum depth of 1 300 m. The "Banana Hole" lies north of the ridges extending between Greenland, Iceland and Scotland; its waters below 1 000 m are therefore of Arctic origin and very cold, with temperatures of -0.9 °C. The fauna here is different to that found at equivalent depths in the Atlantic basins (Bergstad, 2013; Figure 5.2b).

The oceanic portion of the Atlantic high seas is mostly very deep and includes only some 14 000 km^2 of seabed shallower than 400 m; it therefore sees little fishing for conventional, continental shelf resources. It does, however, include nearly 400 000 km^2 of seabed with a depth range of 400–2 000 m, providing potential for deep fishing.

The Rockall Plateau is the principal area of seabed at fishable depths in the high seas, and includes the large Rockall and Hatton Banks as well as a number of minor ones. A ridge and further small banks connect it to the Faroe Plateau (Figure 5.2c). Rockall Bank includes a small shoal area shallower than 200 m, on which stands the Rockall islet itself; it then gradually deepens to a depth of about 500 m towards the southwest. Hatton Bank, on the northern side of the Plateau, is consistently deeper than 500 m and deepens southwestwards. Hatton Basin lies between the two banks at 1 000–1 500 m. While the Plateau thus offers an extensive area of bottom at deep, but potentially fishable, depths, much of it is rough and difficult to trawl. The ratification of the 1982 United Nations Convention on the Law of the Sea by the United Kingdom of Great

TABLE 5.1
High seas bottom fisheries catch in the northeast Atlantic Ocean for 2016

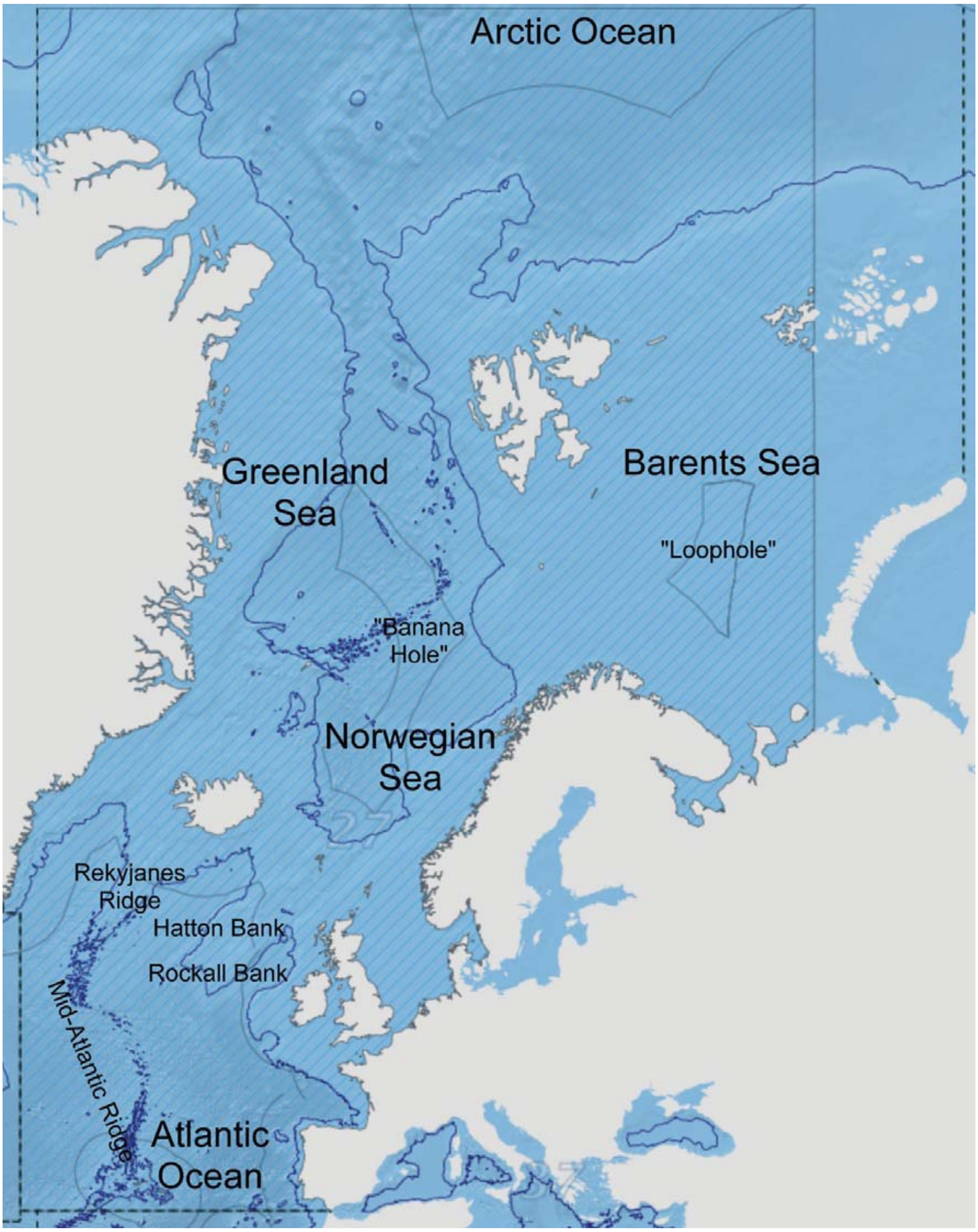
Gear	Ground	Principal NEAFC contracting parties (or flag State)	Species	Catch (tonnes)	Source
Bottom trawl	Barents Sea "Loophole"	Norway, Russian Federation	Atlantic cod	3 619	ICES AFWG, 2018
			Greenland halibut	368	ICES AFWG, 2018
			saithe	81	ICES AFWG, 2018
		Estonia, Norway, Denmark, Faroe Islands	northern shrimp[1]	7 185	Norway Dir. Fish., pers. com.
Pots	Barents Sea "Loophole"	Norway, Russian Federation, Latvia, Lithuania	snow crab[1]	6 541	Norway Dir. Fish., pers. com.
Bottom and midwater trawl	Rockall and Hatton banks	European Union	roundnose grenadier	923	ICES WGDEEP, 2018
			black scabbardfish	305	ICES WGDEEP, 2018
			blue ling	18	ICES WGDEEP, 2018
Bottom trawl	Rockall Bank	Russian Federation, European Union	haddock[2]	513	NEAFC, 2016a
Longline	Rockall Bank	Norway	ling & tusk	153	ICES WGDEEP, 2018
Bottom and midwater trawl	Mid-Atlantic Ridge	Spain	roundnose grenadier	381	ICES WGDEEP, 2018
			roughhead grenadier	67	ICES WGDEEP, 2018
Bottom trawl and LL	NE Atlantic (10b)	Faroe Islands	alfonsino	48	ICES WGDEEP, 2018
Bottom trawl	Mid-Atlantic Ridge	Faroe Islands	orange roughy	93	ICES WGDEEP, 2018
Bottom gear	NEAFC RA	Various	Baird's Slickhead	400	NEAFC, 2016a
			black (deepwater) cardinal Fish	269	NEAFC, 2016a
			silver scabbard fish (cutless fish)	238	NEAFC, 2016a
			alfonsino	48	WGDEEP, 2018
			blue ling	29	WGDEEP, 2018
			various deep-sea species not included above[2]	265	NEAFC, 2016a
TOTAL				21 544	

[1] From sales slips for landings into Norway only; the actual catch from the area likely higher
[2] Assumes all of the reported high seas haddock is caught here.

TABLE 5.2
Area statistics for the northeast Atlantic Ocean

Geographical area	Surface area (km²)
Total sea area	13 007 000
Area of high seas	5 188 000
Area of high seas shallower than 200 m	16 000
Area of high seas shallower than 400 m	76 000
Area of high seas shallower than 1 000 m	133 000
Area of high seas shallower than 2 000 m	473 000

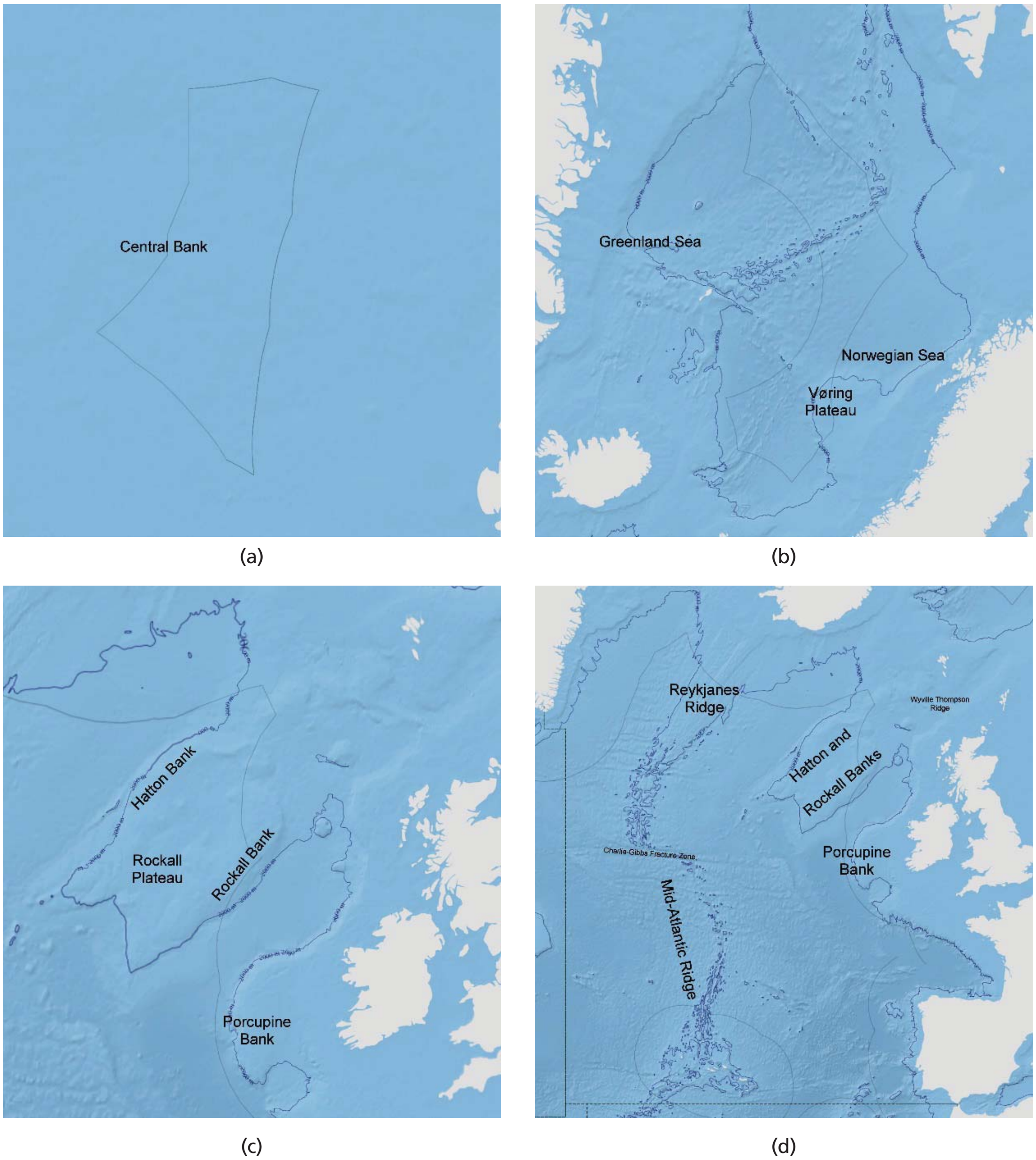
FIGURE 5.1
Map of the northeast Atlantic Ocean showing the NEAFC convention area (shaded)



200 nautical mile arcs, 2 000 m isobath (GEBCO), FAO fishing areas.

Source: FAO VME Database, Mercator projection.

FIGURE 5.2
Features in the NEAFC regulatory area: (a) "Loophole" in the Barents Sea, (b) "Banana Hole" in the Norwegian Sea, (c) detail of Rockall and Hatton Banks in the Atlantic Ocean, and (d) Oceanic area including the Mid-Atlantic Ridge



Source: FAO VME Database.

Britain and Northern Ireland in 1997 removed any extended claims for fishing rights over the Rockall Plateau owing to the existence of the Islet of Rockall; this reduced the size of British fishing grounds, as most of the Rockall Plateau was now in international waters.

The remaining seabed at potentially-fishable depths in the high seas of the northeast Atlantic Ocean is on the MAR and on isolated seamounts. (Figure 5.2d). The MAR is a typical mid-axial rift valley, with secondary ridges and seamounts, and though rugged in places it has extensive areas of gently sloping sedimented seabed (Niedzielski *et al*., 2013). The portion of the MAR extending southwest from Iceland is known as the Reykjanes Ridge. It has a considerable extent of seabed at depths of

200–2 000 m, but is mostly deeper than 500 m outside the Icelandic EEZ and gets progressively deeper towards the southwest. The MAR is interrupted by the Charlie-Gibbs Fracture Zone south of the Reykjanes Ridge. There are only a few scattered summits of ridge-associated seamount complexes extending below 2 000 m deep between the Charlie-Gibbs Fracture Zone and the EEZ around the Azores.

There are also isolated, broadly distributed seamounts away from the MAR, especially towards the southeast, with some at fishable depths.

The northeast Atlantic falls within FAO Major Fishing Area 27. For statistical purposes, ICES has divided this area (excluding the Baltic) into 14 "subareas", which are further divided into "divisions" and "subdivisions". The subareas, divisions and subdivisions which straddle the boundary of the high seas and EEZs were created in 2006 to allow for the separation of international and national catches (Figure 5.3). These are often referred to only by their area numbers, e.g. Area 10, Area 6bi (the high seas portion of Area 6b), or Area 5b67 (three areas combined).

ECOSYSTEMS AND RESOURCE SPECIES

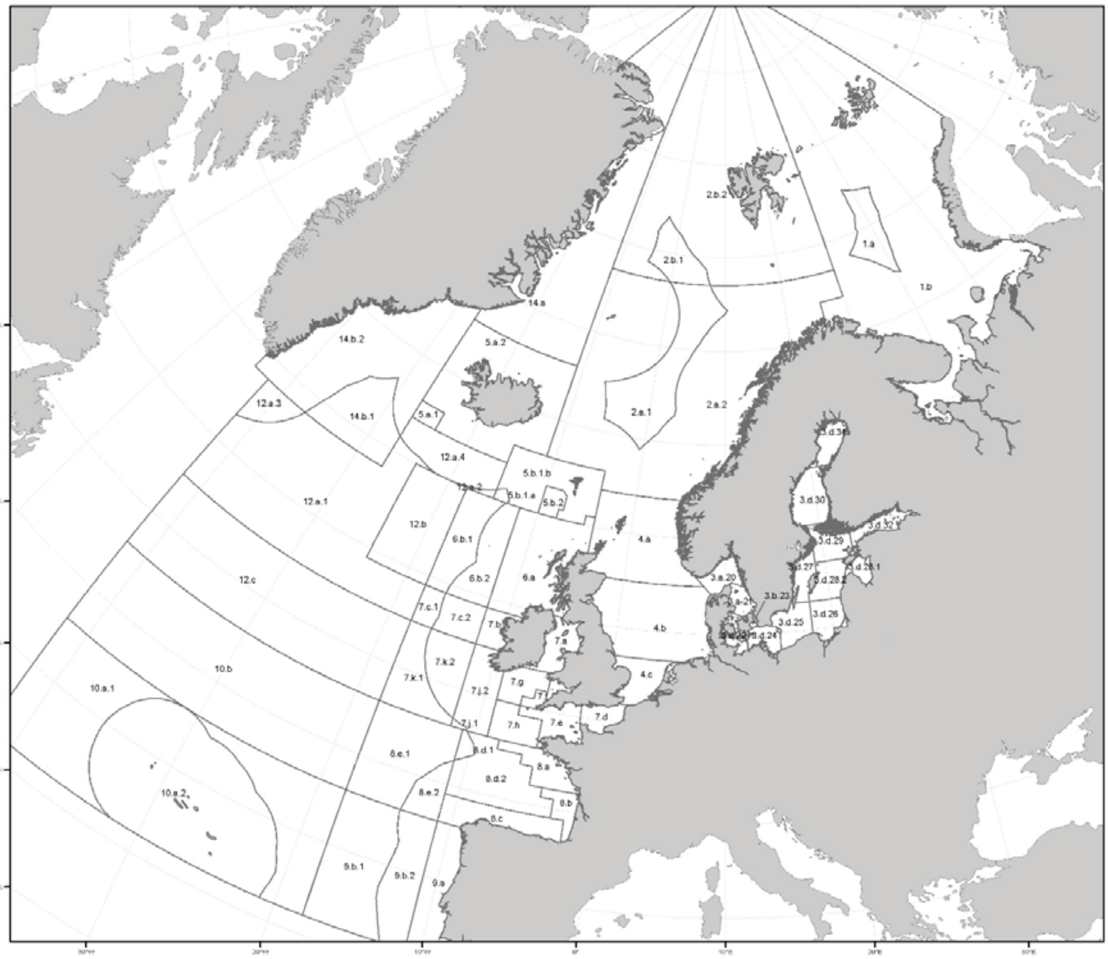
Overview of oceanography

The oceanography of the Atlantic is dominated by the subtropical and subpolar gyres. These are influenced in the northeast Atlantic by the wind-driven North Atlantic Current (NAC), which generally flows east–northeast from the Grand Banks of Newfoundland, passing over the MAR near the Charlie Gibbs Fracture Zone and reaching the European continental margin in the vicinity of the Rockall Plateau. The NAC carries colder, lower-salinity water on its northern side that continues into the Norwegian Sea, and warmer more saline water to the south that feeds the southward Canary Current. These currents are surface features affecting the upper few hundred metres of the water column and only extend directly to the seabed in the continental-shelf depths of the Barents Sea. The NAC has little effect on the benthic ecosystems of the Rockall Plateau and the MAR that lie deeper.

In deeper waters, the subpolar gyre carries Labrador Sea water eastwards, bringing cold, low salinity high oxygen water at around 4 °C to the deeper northern–northeast Atlantic. The subsurface waters under the subtropical gyre are more complex. Locally formed, high salinity, low oxygen North Atlantic Central water (NACW) extends down to depths of several hundred metres and occupies the depth range of the permanent thermocline with widely varying temperatures of 5–20 °C. Beneath the NACW is a layer of cold Antarctic Intermediate water moving northwards from the distant south, which has low oxygen concentrations by the time it reaches the North Atlantic. The warm, highly saline Mediterranean Outflow water pours out through the Strait of Gibraltar and intrudes into the NACW at about 1 000 m depth. It spreads south, west and north, reaching at least as far as Porcupine Bank, west of Ireland. Below this, at depths greater than 1 200 m, is Labrador Sea Water, which floods into the southern northeast Atlantic beneath the NAC and NACW.

At depths greater than 2 000 m, the North Atlantic is flooded by very cold Arctic bottom water that flows over the ridges between Greenland, Iceland and the Faroe Islands from the Norwegian and Greenland seas. The basin water of the Norwegian Sea is -0.9 °C and has a salinity of 34.9 PSU – thus colder and less saline than the North Atlantic proper. That water plunges down the Atlantic side of those ridges creating a large volume of North Atlantic deep water. Additional Arctic water overflows the Wyville Thompson Ridge, between the Faroe Islands and Scotland, and enters the Rockall Trough flowing down its westward side and affecting the southeastern flank of the Rockall Plateau at depths of about 600–1 200 m. The overflow water also spreads between the banks of the Plateau and across the Hatton Basin at the same depths (Johnson *et al.*, 2010).

FIGURE 5.3
ICES Statistical areas showing the newer separation of high seas and EEZs in transboundary reporting areas



Source: ICES website; country boundaries removed, http://ices.dk/marine-data/Documents/Maps/ICES_Areas_maps.zip

Oceanographic variability

The NAC is subject to variations in wind fields caused by changes in air pressure known as the North Atlantic Oscillation (NAO), a pattern of anomalies in the pressure differential between Iceland and the Azores. Positive values of the NAO are associated with a northward displacement of the NAC, which weakens the influence of the subpolar gyre and brings more Atlantic water into the far north. Negative values have the opposite effect. The NAO time series has been reconstructed for the past millennium (Ortega *et al.*, 2015). From the mid-nineteenth century until about 1930, the index was more often positive than negative, though inter-annual variability was high. Thereafter, the index came to average strongly negative, remaining in that state into the early 1970s, after which it was again often positive and particularly so during the years around 1990 (Stige *et al.*, 2006). Ecosystem changes are too complex to be described using a single meteorological index however, and they are best evaluated separately for each high seas fishing ground within the region.

The Barents Sea and its central "Loophole" area were cold during the 1900s and 1910s, warmed rapidly around 1920 and remained generally warm during the 1920s and 1930s, and followed by a slow cooling from 1940–1976. Conditions then became particularly cold until 1982, before returning to a warmer state peaking through the 2000s. The extent of winter ice cover in the central Barents Sea is inversely linked to the temperature index and the inflow of relatively warm water. Ice cover declined to a record low during 2006–2008 (Loeng, 1989; Loeng and Drinkwater, 2007; Dvoretsky and Dvoretsky, 2015). The Polar Front typically lies west and south of the "Loophole" during cold years, leaving that enclave covered by cold Arctic water. In warm years the front lies to the north.

The Rockall Plateau is also affected by changes in the NAO. A positive NAO causes the NAC to flow towards the Norwegian Sea, passing to the west and north of the Rockall Plateau, and allowing warmer surface water to move over it. Conversely, a negative NAO causes the NAC to flow to the south and east, through the Rockall Trough, and allowing colder water from the subpolar gyre to overlie the Plateau. Even minor variations in wind fields can have substantial effects on water flows over and around the Plateau. The subpolar gyre was strong in the early 1990s but weakened sharply after 1995, leading to a pronounced warming of sea-surface temperatures over the Plateau and the waters south of Iceland. The weak subpolar gyre, with much of the NAC flowing west and north of the Plateau, continued through the 2008–2012 period (Childers *et al*., 2015).

The NAC is topographically constrained to cross the MAR via the Charlie Gibbs Fracture Zone and the Faraday Fracture Zone further south (Bower and von Appen, 2008; Priede *et al*., 2013). Thus, the Reykjanes Ridge and MAR north of the Charlie Gibbs Fracture Zone is consistently under the ecologically productive waters of the subpolar gyre, while the more southerly seamounts along and either side of the MAR are consistently under the oligotrophic waters of the subtropical gyre.

Ecology and resource species

The northeast Atlantic has a wide variety of fishable resources and ecosystems. The greatest contribution is from the pelagic fish which are not discussed in this review. Some of the more significant species caught are illustrated in Figure 5.4.

Barents Sea "Loophole"

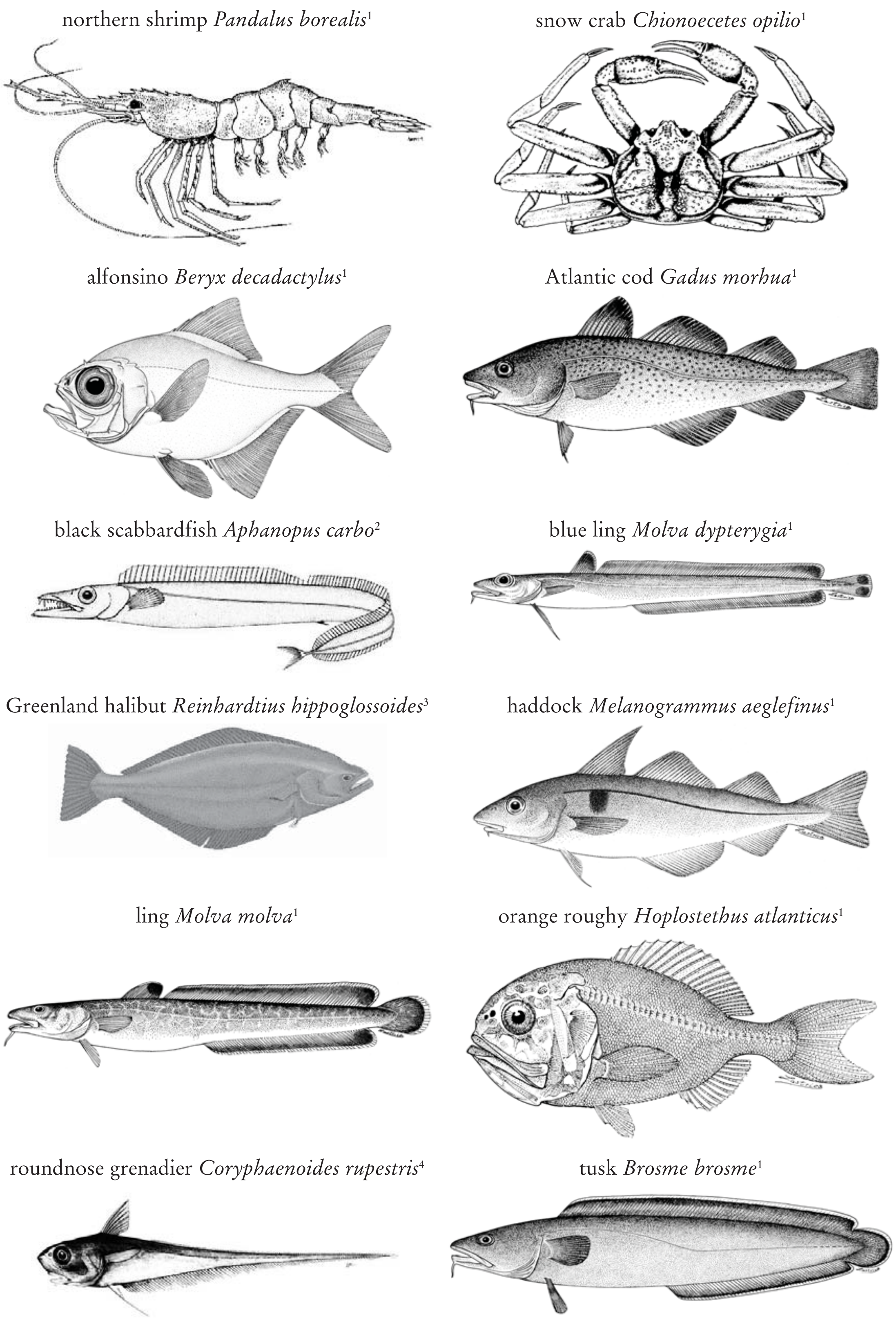
The Barents Sea is shallow, productive and contains the World's most northerly fishing grounds. The Polar Front divides this extensive marginal sea into a cold northeastern and warmer southwestern subarea, and the position of the front is strongly influenced by the variability in inflow of Atlantic water. This variability also causes changes in the timing of plankton blooms and in the distribution of capelin, an important prey for Atlantic cod (Loeng, 1989). The high seas portion of the Barents Sea area is partially flooded by Atlantic water in warm years but lies north and east of the Polar Front during cold periods. The Front itself is a transitional area and a faunal discontinuity, with cod and haddock primarily found in the Atlantic water to its south and west (Loeng, 1989; Loeng and Drinkwater, 2007; Fossheim *et al.*, 2006).

The demersal fish resource in the Loophole comprises only a small fraction of the total Barents Sea resources. The main fish resource are Atlantic cod, followed by haddock, saithe and Greenland halibut. The shellfish resources are the comparatively abundant northern shrimp and snow crab. The bottom fisheries in the high seas of the Barents Sea are mostly for shellfish, with relatively small catches of groundfish and deep-sea species. Snow crab is not native and was first reported in the Barents Sea in 1996. Ovigerous females were first seen in 2004 and the population and associated fishery has increased rapidly since then.

Rockall Plateau

The Rockall Bank, at depths greater than 250 m, has an impoverished subset of the assemblage of fish found on the continental shelf west of Scotland. Resource species include haddock, rosefish, lemon sole, American plaice (known as "long rough dab" in Europe), megrim and monkfish (Neat and Campbell, 2011). The long-established

FIGURE 5.4
Principal demersal resource species of the high seas of the northeast Atlantic



Source:
[1] Food and Agriculture Organization of the United Nations, Original Scientific Illustrations Archive.
[2] www.fao.org/fishery/species/2469/en
[3] www.fao.org/fishery/species/2544/en
[4] www.fao.org/fishery/species/3035/en

bottom fishery around Rockall has been for haddock, conducted both in the high seas and the British EEZ (Blacker, 1982), though with a secondary catch of Atlantic cod which is now scarce. Other well-established fisheries on the Bank are for ling and tusk, though these are typically fished at greater depths. There are also small fisheries on Atlantic halibut, monkfish, saithe, greater forkbeard, and some flatfish and skates. The productivity of the Rockall Plateau is affected by changes in the NAO, and changes to the biota have been observed at trophic levels from phytoplankton to toothed whales (Hátún *et al*., 2009).

Most of the high seas grounds on the Plateau are at much greater depths than the 200 m typical of shelf breaks. Deeper-living species have been targeted using bottom gears and deep midwater trawls. The most important bottom fishing target species, in quantitative terms, has been roundnose grenadier. Others have included: blue ling, black scabbardfish, Baird's slickhead, roughhead grenadier, Greenland halibut, blue whiting, greater argentine, various deep-living sharks (primarily leafscale gulper shark and Portuguese dogfish – collectively referred to as "siki sharks"), chimaeras, red crab (in small amounts) and, briefly, veined squid.

Reykjanes Ridge

The high seas grounds on the Reykjanes Ridge are mostly deeper than 500 m and do not support continental-shelf species. The resources fished there are similar to those taken at equivalent depths on the Rockall Plateau. Roundnose grenadier has been the most quantitatively important. Others have included: tusk, black scabbardfish, roughhead grenadier, various deep-living sharks, blue ling at the northern shallower end, and redfish at the southern deep end.

Mid-Atlantic Ridge south of the Charlie-Gibbs Fracture Zone, in addition to isolated seamounts

The principal bottom-associated resources near and south of the Charlie-Gibbs Fracture Zone, both along the MAR and on the isolated seamounts, are alfonsino and orange roughy. Sporadic bottom trawl and longline fisheries have also occurred for other species such as cardinal fish, tusk, 'giant' redfish, and silver scabbardfish, but these were more exploratory in nature.

MANAGEMENT OF HIGH SEAS FISHERIES

North East Atlantic Fisheries Commission (NEAFC)

The 1959 North East Atlantic Fisheries Convention entered into force in 1963 and created the North East Atlantic Fisheries Commission (NEAFC). In 1980 it was replaced by the Convention on Future Multilateral Cooperation in the North East Atlantic Fisheries, which was still under the NEAFC name. Various amendments were proposed to the Convention in 2004 and 2006 in order to encompass the modern ideology for managing fisheries that includes:

> *the long-term conservation and optimum utilization of the fishery resources in the Convention Area, providing sustainable economic, environmental and social benefits, [...] to take due account of the need to conserve marine biological diversity.*

The NEAFC convention area includes both the high seas and the EEZs of the northeast Atlantic, but the area beyond the EEZs is often referred to as the NEAFC regulatory area, in which the organization has the mandate to manage fisheries for all resource species except tuna and tuna-like species, pelagic sharks, salmonids and marine mammals. NEAFC operates on the principle of a precautionary approach and the need to base management decisions on the best scientific evidence available, as required by the 1982 United Nations Convention on the Law of the Sea.

As described above, there are four high seas areas outside the EEZs of the northeast Atlantic (Figure 5.5). There are no fisheries in the central Arctic area and virtually no bottom fisheries in the “Banana Hole”. The management of the bottom fisheries in the “Loophole” is traditionally undertaken by the Joint Norwegian-Russian Federation Fisheries Commission (JointFish) and as part of wider management frameworks encompassing fisheries harvesting shared stocks occurring primarily within EEZ waters. Arrangements to manage snow crab (a sedentary species) are under development. NEAFC responsibilities are therefore primarily focused on one high seas area in the open Atlantic.

The NEAFC Convention applies to all fish, molluscs and crustaceans, including sedentary species, other than those highly migratory and anadromous species subject to other international agreements. NEAFC has classified the regulated resources as “Pelagic and Oceanic Species” and “Deep-Sea Species” (NEAFC, 2018). The only resource in the first category taken in bottom fisheries is haddock, which is fished on Rockall Bank using bottom gears. The “deep-sea species” list includes 25 teleosts, 23 elasmobranchs and one crab (Table 5.3).

General approach for fisheries for deep-sea resources

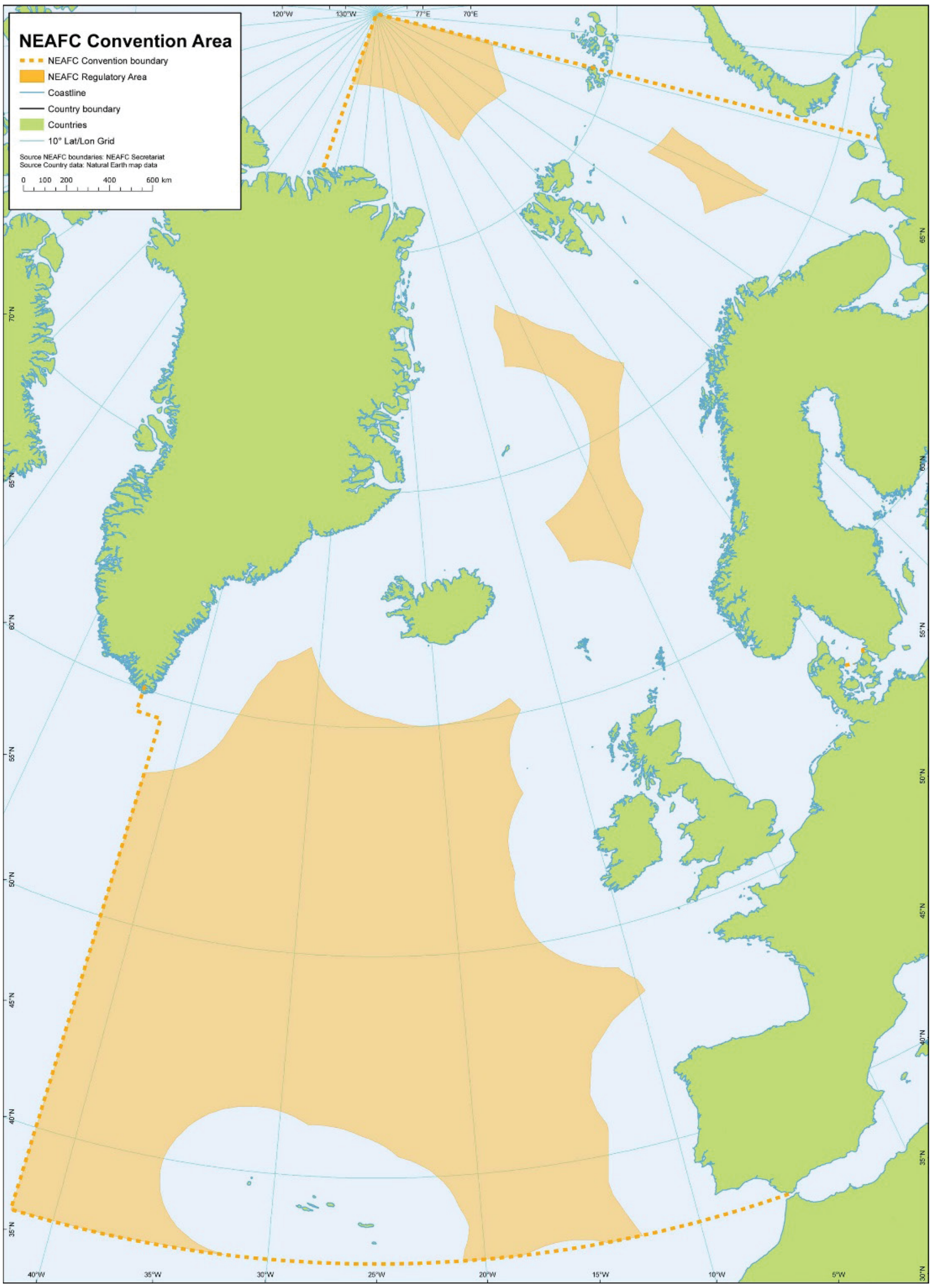
In 2003 the NEAFC adopted a general measure for each Contracting Party to cap their level of fishing effort directed at deep-sea species so as not to exceed the highest level in previous years (NEAFC Rec. 03:2003). This measure has been rolled over each year since, though the cap was dropped to 70 percent in 2005 and 65 percent in 2007. This measure ensures than no new fisheries develop for these species.

NEAFC is receiving scientific advice on a wide range of fish stocks, most of which have relatively small catches in the high seas relative to the EEZ catches (Table 5.4). Most of the fishery was therefore not under the responsibilities of NEAFC (though cooperative joint management is undertaken when possible). Stocks of roundnose grenadier, tusk, orange roughy and roughhead grenadier on the MAR occur almost exclusively in the high seas international waters of the northeast Atlantic. Other deep-sea fished stocks are mainly fished outside of the NEAFC regulatory area – i.e. in the EEZs – and their management therefore rests with the coastal states. The proportion caught in the NEAFC regulatory area can also vary substantially from year-to-year. More examples are given in the text where this applies to other stocks not on the NEAFC deep-sea species list: for example, northeast Arctic (NEA) cod and haddock in the Barents Sea “Loophole”.

In 2016 NEAFC adopted a new approach and categorized its “deep-sea species” and stocks (management units) into four categories, according to the advice provided and the management measure that would be required (NEAFC, 2016b):

1. **Stock-specific measures.** This should apply to stocks for which ICES provides stock-specific catch level advice based on established stock definitions and where the entire or a significant proportion of the catch is taken in the NEAFC regulatory area. Such measures may be of varying nature, but should typically specify catch limits for fisheries in the NEAFC regulatory area.
2. **Measures stipulating that directed fisheries are not authorised and that bycatch should be minimised.** This should apply to stocks for which the ICES advice statement is “no directed fishery, minimize bycatch” or similar, but for which no specific catch limit is advised.
3. **Measures to respond in a timely and adequate manner to new deep-sea species fishing activity within the NEAFC regulatory area.** This should apply to developing fisheries targeting previously unexploited or lightly exploited species/stocks. NEAFC should prevent unregulated expansion of deepwater fisheries even before information has been gathered to facilitate ICES assessment and advice. Pending ICES advice facilitating stock-specific measures

FIGURE 5.5
Map of northeast Atlantic showing the NEAFC convention and regulatory areas



Source: NEAFC website; country boundaries removed, https://www.neafc.org/system/files/neafc-conv-and-ra_0.jpg as in bullet point 1, such fisheries should be regulated with a precautionary catch limit, preferably but not necessarily advised by ICES.

4. **Measures for fisheries primarily restricted to EEZs**. NEAFC regulatory area measures may in such cases be irrelevant and could at most be complementary to coastal state conservation and management measures. If a NEAFC measure is deemed necessary or useful, the aim of such a measure would be to complement EEZ measures in order to ensure that total catches remain within, for example, catch limits advised by ICES.

A provisional categorization of the deep-sea species and stocks proposed by NEAFC was evaluated by ICES and then adopted. The first category is represented only by roundnose grenadier on the MAR and on the Rockall Plateau, plus orange roughy on the MAR alone. Only alfonsino on the MAR and on isolated seamounts have been placed in the third category, but others may enter this category should new fisheries emerge for species that are not currently exploited. All other species and stocks (i.e. those not on the NEAFC deep-sea species list) are either closed to directed fishing or else primarily fished within EEZs where the relevant coastal state has the management authority and responsibility. This approach will assist NEAFC in prioritizing its future management of deep-sea species (Table 5.3).

At the commission's 2017 meeting the measures were updated for most resources in Categories 1 and 2; furthermore, the adoption of a new measure for Category 3 stocks/fisheries was agreed. This was adopted alongside the general management approach that "effort shall not exceed 65 percent of the highest level put into deep-sea fishing in previous years". Thus, as of 2018, NEAFC strengthened the commitment of its contracting parties to ensure that deep-sea fisheries are managed sustainably, according to the precautionary approach (NEAFC Rec. 7:2018).

Specific measures adopted by NEAFC to regulate deep-sea species fisheries and bottom fishing

NEAFC was the first RFMO/A to adopt closures to protect vulnerable marine ecosystems (VMEs) and develop a set of general regulations, including exploratory fishing and encounter protocols, as well as defining "existing bottom fishing areas" in order to identify and protect VMEs (Figure 5.6). NEAFC has adopted TACs and "no directed fishing" bans (sometimes stated as zero TAC) for several species, and also maintains seasonal or full-year closures to fishing with some or all bottom contact fishing gears to protect haddock juveniles and blue ling spawners.

A full record of the measures adopted by NEAFC pertinent to high seas bottom fisheries, from 2005 to the present, is provided in Table 5.5. They have been assigned to three groups: (1) bans on directed fishing whereby the species cannot be targeted but catches are permissible as bycatch (though should be kept to the lowest possible levels); (2) certain catch or effort restrictions applying to the stocks or contracting parties; and (3) various other regulations including closures and gear restrictions, including a gillnet ban beyond 600 m.

Bans on directed fishing were applied to certain specified areas/stocks: for orange roughy in 2007, spurdog in 2009, and various grenadiers in 2016. These have been supported for the same species in other areas by TAC restrictions since 2007 for orange roughy and 2014 for grenadiers. The management of orange roughy has been contentious in the high seas of the northeast Atlantic and currently no agreed management actions have been adopted since 2017. Further, the TACs for grenadier are not binding on vessels from the European Union, as a result of objections. The European Union sets its own TACs and prohibitions for a number of species, which can differ from those adopted by NEAFC (EU, 2018).

TABLE 5.3

NEAFC list of "deep-sea species" split by ICES management units with the 2016 category assignments

NEAFC vernacular name	ICES Stock/ Management Unit and Areas of Distribution (ICES areas)	NEAFC category
Bony fish (Teleosts)		
Baird's slickhead	1–14	4
Risso's smooth-head	1–14	4
blue antimora	1–14	4
black scabbard fish	Entire RA	4
greater silver smelt	Entire RA	4
alfonsinos	6–9	4
	Seamounts and ridges in RA (10a1b, 12a1b)	3
	10a2	4
tusk	1, 2	4
	14, 5a	4
	12, excl. 12b	2
	4, 7–9, 3a, 5b, 6a, 12b	4
	6b	4
conger eel	1–14	4
roundnose grenadier	3a	4
	10b, 12a1c, 14b1, 5a1	1
	1, 2, 4, 5a2, 8, 9, 14ab2	4
	5b, 6, 7, 12b	1
black cardinal fish	1–14	4
bluemouth	1–14	4
orange roughy	6, 7	2
	10	1
silver roughy	1–14	4
silver scabbard fish	1–14	4
eelpout	1–14	
eelpout	1–14	4
roughhead grenadier	4, 12, 14 (main area)	2
	other areas	4
blue ling	5a, 14	4
	1, 2, 3a, 4a2, 8, 9, 12	2
	5b, 6, 7	4
ling	5a	4
	5b	4
	1, 2	4
	All other areas	4
Bony fish (Teleosts) ctd		
common mora	1–14	4
red seabream	1–14	4
Greater forkbeard	1–14	
forkbeards	1–14	4
wreckfish	1–14	4
Greenland halibut	1–14	4
small redfish (Norway haddock)	1–14	4
spiny scorpionfish	1–14	4
Sharks, rays and chimaeras (Elasmobranchs)		
Iceland catshark	1–14	2
gulper shark	1–14	2
leafscale gulper shark	1–14	2
black dogfish	1–14	2
Portuguese dogfish	1–14	2
longnose velvet dogfish	1–14	2
rabbit fish (Rattail)	1–14	2
frilled shark	1–14	2
kitefin shark	1–14	2
birdbeak dogfish	1–14	2
Lantern sharks	1–14	
greater lantern shark	1–14	2
velvet belly	1–14	2
blackmouth dogfish	1–14	2
mouse catshark	1–14	2
buntnose six-gilled shark	1–14	2
large-eyed rabbit fish	1–14	2
sailfin roughshark	1–14	2
round skate	1–14	2
Arctic skate	1–14	2
Norwegian skate	1–14	2
straightnose rabbitfish	1–14	2
knifetooth dogfish	1–14	2
Greenland shark	1–14	
Crustacean		
deepwater red crab	1–14	*

* not currently categorized.

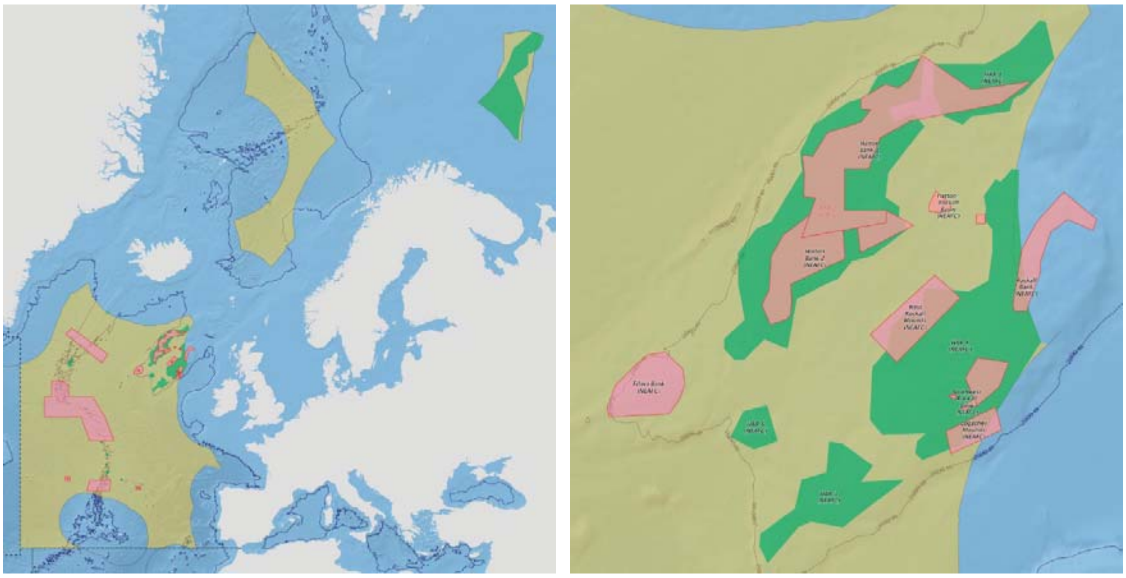
Source: NEAFC, 2016b; Annex 1b, NEAFC, 2018.

TABLE 5.4
Contribution of the high seas regulatory area (RA) to landings of NEAFC deep-sea species and other selected demersal species from the northeast Atlantic Ocean

Species and ICES area	Percentage of landings taken in the NEAFC RA		
	2012	*2013*	*2014*
NEAFC deep-sea species			
Alfonsino – all areas	2	0	0
Black scabbardfish – other stocks	0	0	100
Black scabbardfish – 5b, 6, 7, 12	38	17	9
Blue ling – other stocks	56	54	33
Blue ling – 5b, 6, 7	20	1	0
Greenland halibut – 1, 2	0	0.2	1
Ling – other stocks	0	1	
Orange roughy – MAR	100	0	100
Roughhead grenadier		95	100
Roundnose grenadier – MAR	100	100	100
Roundnose grenadier – 5b, 6, 7, 12b	71	74	61
Tusk – MAR	100	-	-
Tusk – other areas	0	0	
Tusk – 6b	0	16	
Other spp			
Haddock in 6b	4	15	-
NEA cod in 1, 2	< 0.1	0.2	< 0.1
NEA haddock in 1, 2	< 0.1	< 0.1	0

Source: ICES, 2015, ICES AFWG, 2016.

FIGURE 5.6
Bottom fishing measures in the northeast Atlantic adopted by NEAFC in 2018 for: (a) NEAFC regulatory area, and (b) detail of Hatton and Rockall Banks area



(a) (b)

NEAFC "Existing Bottom Fishing Areas" (green) where encounter protocols apply,
areas outside of the "Existing bottom fishing areas" where exploratory fishing protocols apply,
areas closed to bottom fishing to protect known or likely VMEs

Source: FAO, 2019.

TABLE 5.5
Measures adopted by NEAFC since 2005 pertinent to high seas bottom fisheries

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Bans on directed fishing														
Deep-sea Sharks: directed fishing ban for spp on Annex 1b list (Table 6.3)								7:2012	7:2013	→	→	→	10:2017	→
Deep-sea rays (Rajiformes): directed fishing ban for spp on Annex 1b list (Table 6.3)													11:2017	→
Deep-sea Chimaeras: directed fishing ban for spp on Annex 1b list (Table 6.3)													12:2017	→
Orange roughy: specified area restrictions for no directed fishing, and to minimize bycatch			8:2007	8:2008	→	9:2010	→		6:2013	→		6:2016		
Grenadiers MAR: Other grenadiers – no directed fishing												4:2016*	8:2017*	8:2018*
Grenadiers – Hatton Bank and Rockall: no directed fishing												5:2016*	9:2017*	9:2018*
Spurdog: no directed fishing					8:2009	7:2010	7:2011	5:2012	→	→	8:2015	→	13:2017	→
Effort and TAC restrictions														
Deep-sea species: effort limitations at 65% of highest level (70% for 2005 & 2006) (100% for 2003 & 2004) (from 2003)	3:2005	9:2006	6:2007	15:2008	7:2009	6:2010	→	→	4:2013	3:2014	3:2015	3:2016	6:2017	6:2018
Orange roughy: catch restriction for contracting parties for specified areas			8:2007	8:2008	→	9:2010	→		6:2013	→				
Grenadiers MAR: Roundnose grenadier - TAC										4:2014*	4:2015*	4:2016*	8:2017*	8:2018*
Grenadiers MAR: Roughhead grenadier – TAC											5:2015*			
Grenadiers – Hatton Bank and Rockall: TACs												5:2016*	9:2017*	9:2018*
Other measures including closures														
Rockall Haddock: area closed to all fishing except longlines (from 2002)	4:2003	→	5:2007	5:2008	5:2009	4:2010	4:2011	→	3:2013	2:2014	2:2015	2:2016	5:2017	5:2018
Blue ling seasonal closures: on Reykjanes Ridge to all bottom-contact gear to protect blue ling						10:2010	→	→	5:2013	→	→	→	7:2017	→
VME protection in regulatory area: various region-wide protection measures including closures and bottom fishing restrictions	5:2005	10:2006	9:2007 10:2007	16:2008 9:2008	pv:2009 pv:2009 13:2009 14:2009	pv:2010 8:2010 11:2010	15:2011 na:2011 14:2011	8:2012	8:2013 9:2013 12:2013	19:2014	→ (9:2015)	→	→	→
Discards ban: a ban on discarding or releasing species on the Annex 1a list [Pelagic and Oceanic spp.]						16:2010	→	→	→	→	→	→	→	→
Gillnets: A ban on setting gillnets, entangling nets or trammels anywhere with a bottom depth greater than 200 m		3:2006	→	→	→	→	→	→	→	→	→	→	→	→
Shrimp: sorting grids											11:2015	→	→	→

Blank cell indicates no measure;
→ indicates measure rolled over to next year. Note that not all measures were in force for the complete year
* European Union raised an objection to this measure
Source: see http://www.neafc.org/managing_fisheries/measures for details.

Joint Norwegian–Russian Fisheries Commission (JointFish) – bilateral management for the Barents Sea

Resources in the Barents Sea and northern Norwegian Sea are primarily harvested by Norway and the Russian Federation within EEZs and managed cooperatively with the Norwegian–Russian Fisheries Commission (JointFish). JointFish makes consensus recommendations of TACs for Atlantic cod, haddock, Greenland halibut, redfish, capelin, herring and other species, allocating quotas to the two coastal states and to third parties. JointFish has also been involved with mesh size, sorting grids, satellite monitoring and more. However, some aspects of management remain with NEAFC, such as the port-control system and protection of VMEs.

International Council for the Exploration of the Sea (ICES) – Independent scientific support

ICES is an independent intergovernmental science organization that provides scientific advice to, among others, NEAFC and JointFish. ICES has no fisheries management, compliance or enforcement responsibilities.

The advisory scientific work undertaken by ICES of relevance to this review is primarily carried out by "Expert Groups", of which the following are most relevant to high seas bottom fisheries:

- Working Group on the Biology and Assessment of Deep-Sea Fisheries Resources (WGDEEP)
- ICES–NAFO Joint Working Group on Deep Water Ecology (WGDEC)
- Arctic Fisheries Working Group (AFWG)
- North-Western Working Group (NWWG)
- Working Group on Elasmobranch Fishes (WGEF)
- Working Group on the Assessment of Northern Shelf Demersal Stocks (WGNSDS)
- Working Group on Ecosystem Effects of Fishing Activities (WGECO).

The Expert Groups provide the technical background for the scientific advice, and the advice is released by the ICES Advisory Committee on Management. ICES publishes its advice online and also presents its advice at the annual NEAFC Commission meetings.

ICES now classifies stocks based on the type of information available for their assessments (ICES, 2016). The northeast Arctic cod and haddock, Rockall haddock, and Greenland halibut stocks are the only resources partially harvested by bottom fishing in the high seas where full quantitative assessment are undertaken (classified by ICES as "Category 1"). Most of the other stocks are far less well-known, having at best indications of biomass trends from surveys (ICES "Category 3") and often only landings – not catch – data (ICES "Category 5"). Further details on most of the fisheries discussed here, and the regularly updated scientific advice, can be found on the ICES website.

ICES has provided advice to NEAFC on deep-sea stocks since 2006, typically every two years, and summaries can be found in the appropriate appendix of the annual NEAFC Commission reports. Advice up until 2010 was qualitative in nature and referred to perceived status and trends, and included expressions such as "maintain catch at recent levels". In 2012, a new approach was adopted whereby quantitative assessments, even for data-limited stocks, were provided whenever possible, often in the form of a TAC advice. ICES provides its advice by fish stocks agreed internally, often with reference to distributions according to ICES statistical subareas and divisions. Whereas this may be appropriate for defining management units, in practice it creates management challenges when stocks straddle the EEZ/high seas boundary, particularly when almost all of the stock rests within the EEZs.

HIGH SEAS BOTTOM FISHERIES

History

There are records of deep longline bottom fishing in the deep shelf area off the Norwegian coast from the sixteenth century. However, the modern history, using fishing methods similar to those of today, really commenced with the advent of deep trawling on the continental slope southwest of Ireland around 1905. Trawling for deep-living, slow-growing resources was pioneered by the redfish fisheries of the *Rosengarten* and the Barents Sea after 1920 (Jenkins, 1920; Alward, 1932; Maslov, 1944; Lundbeck, 1955; Sahrhage and Lundbeck, 1992; Bergstad and Hareide, 1996; Magnússon, 1998). The pioneering expansion and exploratory fishing in the northeast Atlantic by the former USSR in the 1960s and 1970s led to the discovery of the principal significant resources: roundnose grenadier, alfonsino, blue whiting, redfish, and Greenland halibut. It is less clear when European fleets started bottom fishing in what are now the northeast Atlantic high seas. European fleets expanded activities westward beyond current EEZs in the 1980s and 1990s, where exploration for new resources was supported by both publicly funded research and commercial interests. These initial efforts resulted in multiple, short-lived and small-scale yet quasi-commercial fisheries, amid a few full-scale examples. The high seas fisheries were attractive for another reason, as until recently bottom fisheries were largely unregulated in terms of access and catch volume, yet still relatively close to major markets. The boundaries of national jurisdictions, and hence the high seas/EEZs boundary, as they currently exist, had little relevance to the early development of these fisheries. Most of those boundaries were not established until the late 1970s (those across the Rockall Plateau were not established until 1997).

In 2006, to help with data collection, ICES divided each of its straddling statistical areas into separate high seas and national components. Even now, that requires some informed judgment by the members of ICES Working Groups, who interpret the landings statistics submitted by individual members to ICES. Best information on landings available to ICES for most of the species/stocks fished partly or wholly in the high seas of the northeast Atlantic was compiled for the years 2012–2014 (ICES, 2015; Table 5.6). Moreover, NEAFC publishes official landing statistics submitted by its contracting parties, and from 2012 onwards the landings were split by jurisdictions so that the landings from the high seas were available for all species, including for deep-sea species. For some relatively recent years (at least 2010–2012), there were major discrepancies between the ICES landings figures and landings reported to NEAFC – this was discussed in 2017 in a report from the ad hoc NEAFC Working Group on Deep-Sea Species, which is mandated to compile historical landings and effort statistics for areas outside EEZs (NEAFC DSS, 2017). This was a serious issue, but the discrepancies seem to have been significantly reduced in recent years. It is important to note, however, that several of the deep-sea species are fished with midwater gears, the statistics are thus not fully representative for bottom fisheries.

Overall trends in the high seas of the northeast Atlantic

The principal countries fishing in the NEAFC regulatory area, including the Barents Sea and in the Atlantic proper, are the European Union, Norway, Faroe Islands and Russian Federation, with the former taking 81 percent of the landed catch for all gears combined in the 2003–2015 period (Figure 5.7). It is very difficult to compare fishing effort between countries by virtue of the different methods used to determine effort; very approximately, the relative catches can be used to estimate and assign relative effort among these four countries. Greenland and Iceland did not fish in the NEAFC regulatory area during the 2003–2017 period. The most important gear used to fish deep-sea species was the bottom trawl, followed by longlines, in addition to the occasional use of gillnets and other bottom set fishing gears by the European Union (Figure 5.8). Each of these graphs provides a good indication of trends in effort,

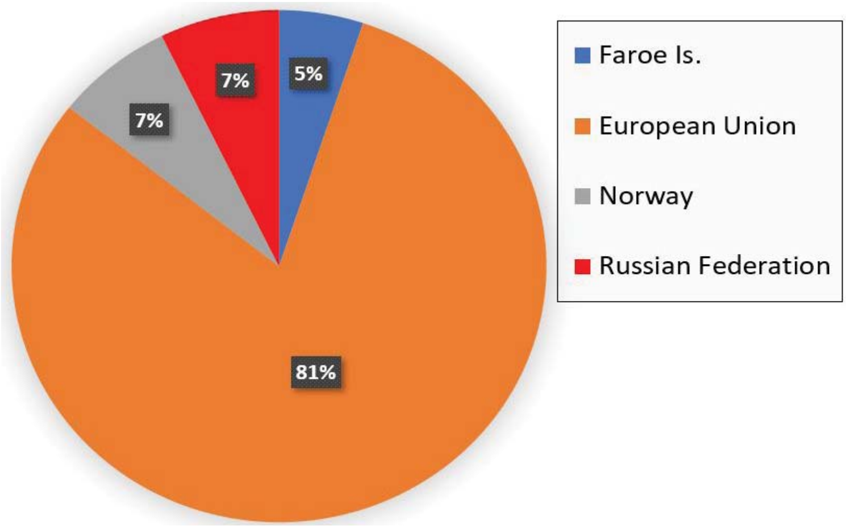
TABLE 5.6
ICES estimates of landings (tonnes) of various fish stocks taken by bottom fishing in the NEAFC regulatory area

Species	Landings			Location of Fishery	Source(s)
	2012	2013	2014		
NEA cod	379	2 207	534	Loophole: 1a	ICES, 2015; ICES AFWG, 2016
NEA haddock	5	39	0	Loophole: 1a	ICES, 2015; ICES AFWG, 2016
NEA saithe	0	0	0	Loophole: 1a	ICES, 2015; ICES AFWG, 2016
Greenland halibut	0	36	211	Loophole: 1a	ICES, 2015; ICES AFWG, 2016
northern shrimp			6 734	Loophole: 1a	Norwegian Directorate of Fisheries (unpublished information)
snow crab	2.5		c.4 000	Loophole: 1a	Norwegian Directorate of Fisheries (unpublished information); ICES WGCRAB, 2015
haddock	31	142	442	Rockall Bank: 6b	ICES, 2015; NEAFC, 2016a
roundnose grenadier	8 579	2 779	1 261	Rockall, Hatton Banks 6b1, 12b	Mixed deepwater trawl fisheries on Rockall and Hatton Banks: ICES, 2015
black scabbardfish	1 444	549	303	Rockall, Hatton Banks 6b1, 12b	Mixed deepwater trawl fisheries on Rockall and Hatton Banks: ICES, 2015
blue ling	1 344	289	81	Rockall, Hatton, Lousy Banks 5b1a, 6b1, 12b	Mixed deepwater trawl fisheries on Rockall and Hatton Banks, Longline fishery on Lousy Bank: ICES, 2015
ling	0	180	79	Rockall Bank: 6b1	Bycatch species in trawl and longline fisheries. Longline fisheries on Rockall Bank: ICES, 2015
tusk	0	14	10	Rockall, Lousy Banks 5b1a, 6b1	Bycatch species in trawl and longline fisheries: ICES, 2015
longnose velvet dogfish	1	1		Rockall Bank: 6b1	ICES, 2015
roundnose grenadier	9 202	1 789	3 477	Mid-Atlantic Ridge	Recently developed deepwater trawl fishery on the Mid-Atlantic Ridge: ICES, 2015
roughhead grenadier		1 192	655	Mid-Atlantic Ridge, Hatton Bank	Landings reported from the Mid-Atlantic Ridge fishery targeting roundnose grenadier on the Mid-Atlantic Ridge. Also reported from fisheries in the Hatton/Rockall area: ICES, 2015
tusk	18	0	0	Mid-Atlantic Ridge 12, 14	Sporadic small catches have occurred in the past. Bycatch in longline and trawl fisheries: ICES, 2015
orange roughy	167	0	58	Mid-Atlantic Ridge 10, 12	Directed fisheries have occurred on the Mid-Atlantic Ridge and south of Hatton Bank in the past: ICES, 2015
black scabbardfish	4	0	30	Mid-Atlantic Ridge 10, 12	Mainly bycatch from above fisheries: ICES, 2015
alfonsino			110	Mid-Atlantic Ridge 10, 12	Former targeted trawl fishery on seamounts on the Mid-Atlantic Ridge north of the Azores: NEAFC, 2016a
various deep-sea species not included above			1 269	NEAFC RA, all areas	NEAFC, 2016a

which in general fluctuates, but only shows clear patterns in a few cases. The Russian Federation effort for both bottom trawling and longlines, and the European Union longlines and gillnets, showed a clear declining trend with fishing essentially ending by 2010. Whereas, the Faroe Islands have increased their longline effort since 2013. Further details, interpretations, and caveats, are to be found in NEAFC deep-seas species report (NEAFC DSS, 2017).

NEAFC has recently reported on the annual landings of its listed deep-sea species from the high seas for 1970–2015 (Figure 5.9; NEAFC DSS, 2017). Once again however, this report notes data inconsistencies between different submissions, so these catch values should not be treated as definitive estimates. Perhaps the most obvious trends are the strong cycle that goes from low-high-low, which occurred in the 1972–1991 and 1992–2012 periods, with perhaps an indication of rising catches from 2013. The first cycle

FIGURE 5.7
Percentage by weight of the deep-sea species landed for all gears combined for 2003–2015 in the NEAFC regulatory area



Source: Extracted from Figure 8.1 in NEAFC DSS, 2017.

is due to the Russian Federation fishery, which was the only country to exploit the high seas of the northeast Atlantic during this period until 1990 for landings of roundnose grenadier, alfonsino and black scabbardfish from ICES subareas 10 and 12. Thereafter followed the development of various mixed fisheries with a wide range of national participation, which was most likely driven in large part by stricter controls within the EEZs and a relative lack of control in the high seas. The European Union was the main fishing entity during this period. The decline in catches after 2000 is due to a mixture of stock declines, stricter management, and probably changing economic conditions.

Norwegian Sea and the "Banana hole"

The "Banana hole" fishery in the high seas is almost exclusively for pelagic redfish, since it is generally too deep to fish with bottom gear. However, recently there have been reports of catches of cod, saithe and Greenland halibut from the southern portion with 12 tonnes, 11 tonnes and 6 tonnes, reported respectively in 2017, and only 5 tonnes of Greenland halibut in 2016. Bottom trawls, gillnets and longlines are fished in adjacent EEZ waters, and so there may be some limited deep bottom fishing around the Vøring Plateau (ICES AFWG, 2018).

Barents Sea and the "Loophole"

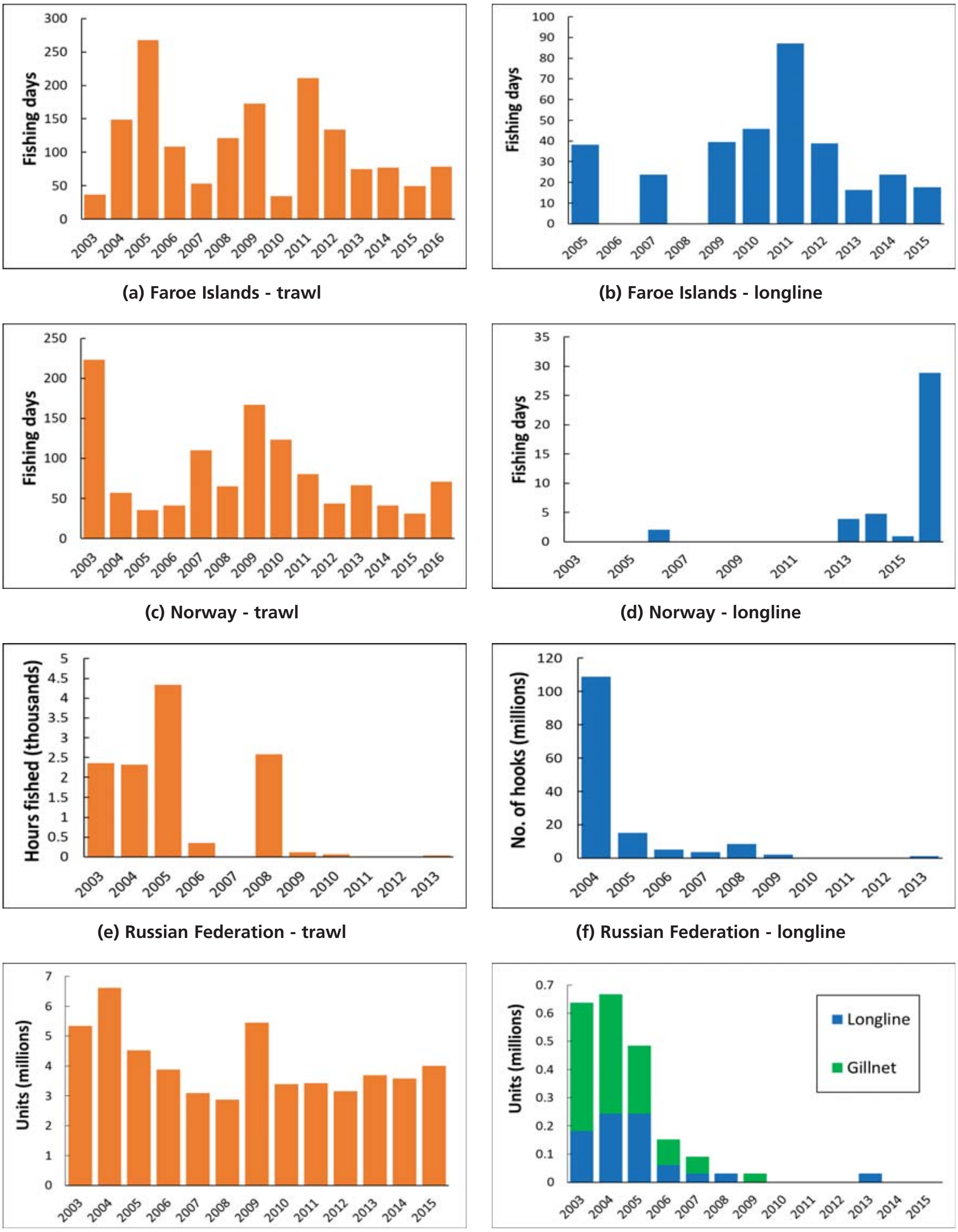
Groundfish trawl fishery

Bottom trawl fishing now mainly occurs in the southwestern portion of the "Loophole" at depths of around 300 m, catching NEA cod, NEA haddock, NEA saithe, and Greenland halibut – though the distribution of effort changed between 2015 and 2017 as a result of new agreements on snow crab between Norway and Russia (Figure 5.10). The catch in the high seas "Loophole" is not normally separated from the overall Barents Sea catches and disaggregation by area can be challenging.

Offshore fishing on the NEA cod feeding grounds started when steam trawlers from British ports extended their operations into the Barents Sea from 1905 (Robinson, 2000). Warmer temperatures in the 1920s and 1930s opened up the extreme northern grounds as far as Svalbard (Robinson, 2000), and may have included fishing on the Central Bank in the "Loophole". This may have ceased during the colder 1940s–1980s period. With the improving resource and an accessible high seas ground, an international

FIGURE 5.8

Fishing effort for NEAFC deep-sea species by the main fishing nations in the NEAFC regulatory area, including the Atlantic Ocean proper and the Barents Sea



(a) Faroe Islands - trawl

(b) Faroe Islands - longline

(c) Norway - trawl

(d) Norway - longline

(e) Russian Federation - trawl

(f) Russian Federation - longline

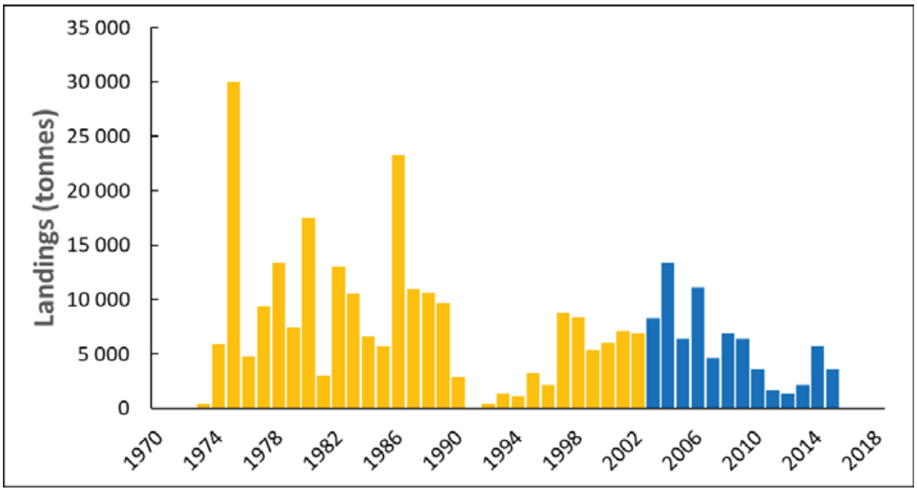
(g) European Union - trawl

(h) European Union - longline and gillnet

Source: NEAFC DSS, 2017. Note that the above data has been rearranged graphically for the purposes of the present review.

FIGURE 5.9

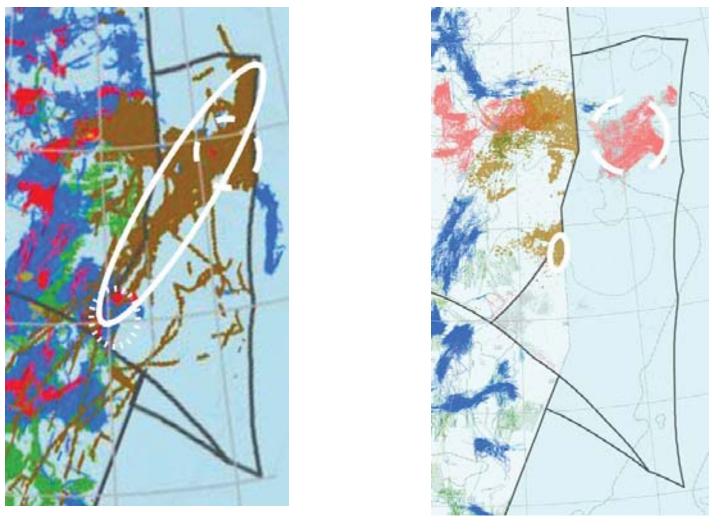
Time-series of annual landings of deep-sea species from the NEAFC regulatory area by all contracting parties, as reported to the NEAFC Deep-sea Species working group in 2003 (yellow bars) and in 2017 (blue bars)



Source: NEAFC DSS, 2017. Note that the above data has been rearranged graphically for the purposes of the present review.

FIGURE 5.10

Bottom fishing in the "loophole" by Norwegian vessels using bottom trawls for cod, haddock, saithe, and Greenland halibut (dotted white) and northern shrimp (dashed white) and pots for snow crab (solid white), in (a) 2015 and (b) 2017



(a) (b)

key: blue = bottom trawl for demersal fish; pink = bottom trawl for shrimp (partially hidden by pot overlay in 2015 plot); green = longlines (not used in the "Loophole"); brown = traps (pots) for snow crab; red = midwater trawls; grey = other.
Source: ICES AFWG, 2016 (a); Directorate of Fisheries, Norway, 2019 pers. comm. (a and b).

fleet including vessels from the European Union Member States, the Faroe Islands and Greenland, began to fish in the "Loophole" in 1991. The fishery expanded rapidly two years later, when Icelandic trawlers (faced with a quota cut in their home waters) moved north – media reports from the period refer to 80 Icelandic vessels working the area by 1995. The "Loophole" cod catch reached 12 000 tonnes in 1993 and peaked at

50 000 tonnes (about seven percent of the Barents Sea cod catch) the following year, before declining rapidly to little more than 2 000 tonnes by 1998 as the stock shifted southwards (Stokke, 2001; Bensch *et al*., 2009).

Groundfish trawling continues in the "Loophole", albeit with annual variations in effort, though only as a very minor component of the much larger Barents Sea fisheries. The principal fish species currently caught is NEA cod. While the total catches of all fish species amounts to a not insubstantial catch by global high seas standards, averaging upwards of 3 300 tonnes per annum for 2012–2015, it is a negligible proportion of total landings from the Barents Sea fisheries – amounting, even in the best years, to one percent or less for cod, haddock, saithe, and Greenland halibut (ICES, 2015; ICES AFWG, 2016). Annual catches of NEA cod, NEA haddock, NEA saithe and Greenland halibut in the "Loophole" have been very variable (Table 5.7).

ICES provides advice for NEA cod (Areas 1 and 2) and sets a recommended catch limit for the entire stock; in 2016, for example, the limit was 805 000 tonnes. This was noted by JointFish who set the actual TAC at 894 000 tonnes. There is no separate management of NEA cod in the "Loophole", though catches here are included in the TAC. The same process was followed for NEA haddock (ICES advised catch of 223 000 tonnes; JointFish adopted TAC of 244 000 tonnes) and Greenland halibut for 2016 (ICES advised catch of 19 800 tonnes; JointFish adopted TAC 22 000 tonnes) again with no separate management plan for the "Loophole" area.

TABLE 5.7
Annual catches (tonnes) NEA cod, haddock and Greenland halibut, in the "Loophole"

Species	2012	2013	2014	2015	2016	2017
NEA cod	379	2 207	534	9 081	3 619	1 212
NEA haddock	5	39	0	702	7	90
NEA saithe	0	0	0	30	81	70
Greenland halibut	0	36	211	55	368	592

Source: ICES, 2015; ICES AFWG, 2016, 2017, 2018.

Shrimp trawl fishery

The Barents Sea trawl fishery for northern shrimp was started by Norwegian vessels in the 1970s and developed as other nations joined. Catches of northern shrimp for the whole Barents Sea peaked at 128 000 tonnes in 1984, but subsequently declined to a much lower level; since 2006, catches have averaged 28 000 tonnes per annum (range: 19 000–36 000 tonnes). Norway and the Russian Federation fish the stock over its entire range, whereas vessels from other nations are restricted to the Svalbard fishery protection zone and the "Loophole".

Since 2007, annual catches in the "Loophole" have been variable, though accurate figures are not available. For 2014, the shrimp catch in the Barents Sea "Loophole" was estimated at 6 734 tonnes, most of which was taken by Norwegian trawlers. This represented 32 percent of the total Barents Sea catch (ICES NIPAG, 2016; Directorate of Fisheries, Norway, personal communication, see Table 5.8). Northern shrimp are now caught mainly by bottom trawls in the northern part of the "Loophole" at some 200–300 m depth (Figure 5.10). The northern shrimp catch in 2016 was estimated at 7 185 tonnes (Directorate of Fisheries, Norway, personal communication).

Northern shrimp in the Barents Sea and Svalbard fishery protection zone are considered one stock. There is no agreed TAC for this stock, and it is not currently managed by NEAFC or JointFish, though there is a partial TAC in the Russian Federation zone. Licenses are required for the Russian Federation and Norwegian vessels, and this provides some form of effort control, though not within the "Loophole". Nevertheless, ICES does assess this stock and provide a recommended catch limit: in 2016 it was set at 70 000 tonnes, well above the catch for that year.

TABLE 5.8
Shrimp catches (tonnes) in the Barents Sea for 2014

Area	Norway	Russian Federation	Others	Total
Loophole	1 245	0[1]	5 489	6 734
Svalbard Protection Zone (SPZ)[2]	8 989	0[1]	4 500	14 230
Barents Sea EEZs (excluding SPZ)		714	0	
Totals	10 234	714	9 989	20 964

[1] Russian catch is believed to be minimal.
[2] Within Norwegian EEZ.
Source: ICES NIPAG, 2016; Directorate of Fisheries, personal communication.

Snow (queen) crab pot fishery

The colonization of the snow (queen) crab in the Barents Sea was first noticed in 1996. Norway began a new snow crab fishery in 2012 with a catch of 2.5 tonnes; it developed rapidly thereafter. The fishery straddles the "Loophole" high seas enclave and waters under national jurisdiction. At present most of the activity has been in the "Loophole", though separation of the catches is not always clear (ICES WGCRAB, 2016). The "Loophole" catch was believed to be around 4 000 tonnes in 2014 and upwards of 4 600 tonnes in 2016. Total Barents Sea catches are substantially higher (Table 5.9, ICES Catch database).[1] The fishery for snow crab on the larger Central Bank area along the western side of the "Loophole uses pots set mainly across a diagonal southwest-northeast band at depths of 150–300 m. In 2017, bilateral agreements resulted in the Norwegian effort being confined to the continental shelf at the southwestern corner of the "Loophole" (Figure 5.10).

As coastal states, Norway and the Russian Federation have recently exerted their jurisdictional claim into the "Loophole" area, over what they define as a sedentary resource on their extended continental shelves. The fishery is now only prosecuted by Norway and the Russian Federation (ICES WGCRAB, 2016). Snow crab in the "Loophole" are not under the management of NEAFC or JointFish. ICES WGCRAB (2016) does not assess or provide advice on this stock, but does record catch statistics and notes that management plans are being developed.

TABLE 5.9
Barents Sea catches (tonnes) of snow (queen) crab

Country	Area		2012	2013	2014	2015
Norway	Loophole (high seas)	1a	0	0	1 749	2 280
Norway	Barents Sea (excluding Loophole)	1b, 2	2	178	133	826
Russian Federation	Barents Sea	1	0	63	4 105	8 917
Latvia	Loophole	1a	0	0	229	3 830
Total	Barents Sea	1, 2	2	241	6 215	15 853

Source: ICES WGCRAB, 2016.

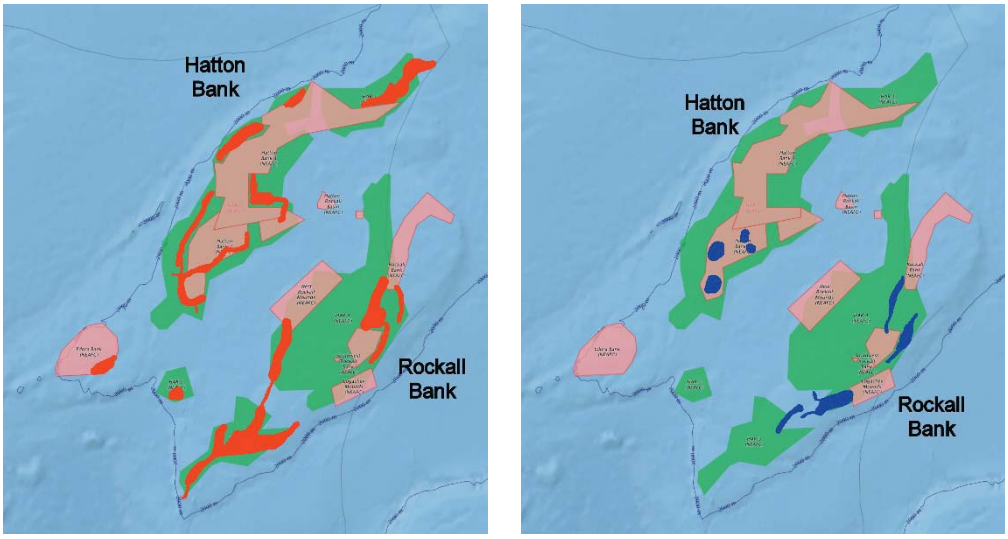
Rockall and Hatton Banks

A variety of fisheries have operated on and around the Rockall and Hatton Banks (Figure 5.11). The following is a summary describing mainly those that have occurred on the high seas portion, though in many cases it can be difficult to separate these from fisheries occurring within the EEZs.

[1] See http://ices.dk/marine-data/Documents/CatchStats/OfficialNominalCatches.zip

FIGURE 5.11

Composite map showing approximate areas for bottom fishing on and around Hatton and Rockall Banks during 2014–2016 for: (a) bottom trawling (solid red), and (b) static gears, mostly longlines (solid dark blue), occurring within the existing fishing areas (green)



(a) (b)

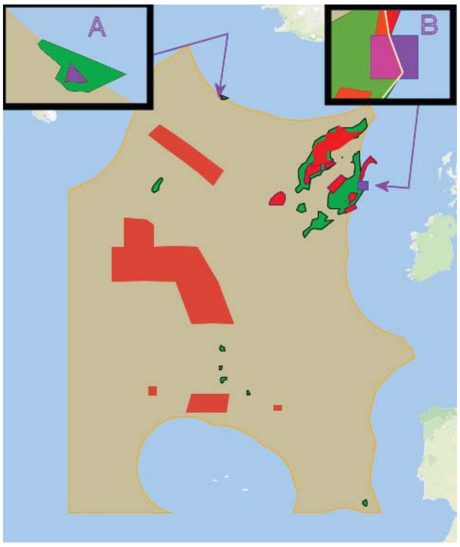
Some VMEs (light red) were adopted after the trawl and longline data was recorded.
Source: See ICES WGDEC (2013–2017) on ICES website for original maps.

Bottom trawl fishery on Rockall Bank for haddock and other species

Commercial fishing over the entire Rockall Bank (including the portion now under national jurisdiction) by the trawlers of the former USSR commenced in 1972 and took 49 000 tonnes of haddock in 1974, 50 000 tonnes the next year and 40 000 tonnes in 1976, together with small amounts of bycatch. The extension of the United Kingdom of Great Britain and Northern Ireland's national jurisdiction in 1977 ended that fishery and catches fell to the few thousand tonnes landed annually, mainly by British trawlers (Blacker, 1982; Newton *et al*., 2008). Most national fleets withdrew from the fishery in the late 1980s, though the English were active until the late 1990s. In contrast, the Scottish fleet dominated during 1985–2000s, catching up to 7 100 tonnes in some years, and the Irish fleet worked the area from 1990. The Russian Federation fleet returned in 1999, following the withdrawal of the extended British jurisdiction two years earlier, taking mostly haddock; by 2003 it dominated the fishery, as Scottish and Irish activity declined under restrictive European Union TACs (Newton *et al*., 2008).

Concerns of high exploitation rates, low stock biomass, excessive mortality on younger fish, and lack of any haddock TAC in the international waters of the Rockall Bank led NEAFC to close an area now known as the "Haddock Box" to all fishing gears except longlines, in order to protect juvenile haddock (Figure 5.12). This closure was first implemented in 2002 and has been maintained through annual extensions. The box spans the EEZ/high seas boundary and includes most of the high seas portion shallower than 200 m (Gordon, 2006). The subsequent trawl fishery in the high seas around Rockall Bank had to move to waters of 200–400 m depth. In 2005, high seas haddock catches comprised 4 700 tonnes taken by Russian Federation trawlers, 375 tonnes by Scottish vessels and 105 tonnes by those from Ireland (Bensch *et al*., 2009). Catches in the same area had fallen to 31 tonnes, 142 tonnes and 442 tonnes for 2012, 2013 and 2014 respectively (ICES, 2015). Bycatch included Atlantic cod, ling, saithe, flatfishes and skates, with the addition of deeper-living species including chimaeras, ling, blue ling, roundnose grenadier, tusk, redfish and rosefish when the fishery moved deeper (Gerritsen and Lordan, 2014).

FIGURE 5.12
NEAFC management measures to protect blue ling (A), with a seasonal closure between 15 February and 15 April since 2010 during the spawning season; and juvenile haddock (B) by closing the area to all fishing



Source: http://www.neafc.org/page/closures

There are occasional brief periods when squid become seasonally abundant around Rockall, causing trawlers to switch target species. This happened in 1970–1974 and 1986–1989 (Newton *et al*., 2008; Arkhipkin *et al*., 2015). The fishery was conducted in small canyons near the islet of Rockall (Newton *et al*., 2008) and hence probably in large part inside the modern British EEZ.

Rockall haddock in Area 6b is regarded as a distinct stock and assessed by ICES as such, with some 4–15 percent of the catches coming from the high seas. Blue ling in Area 5b67, tusk in Area 6b and black scabbardfish in Area 5b6712, are also occasionally caught in the high seas, either on or relatively near to the Rockall Bank (Table 5.4). ICES provides advice on these stocks and the European Union sets a TAC which applies to its vessels, both those fishing within its waters and the high seas. NEAFC does not adopt any stock-specific management measures for these stocks but the generalized measures it applies to parts of these areas (VME measures, general measures for deep-sea species) most likely has a conservation value for them.

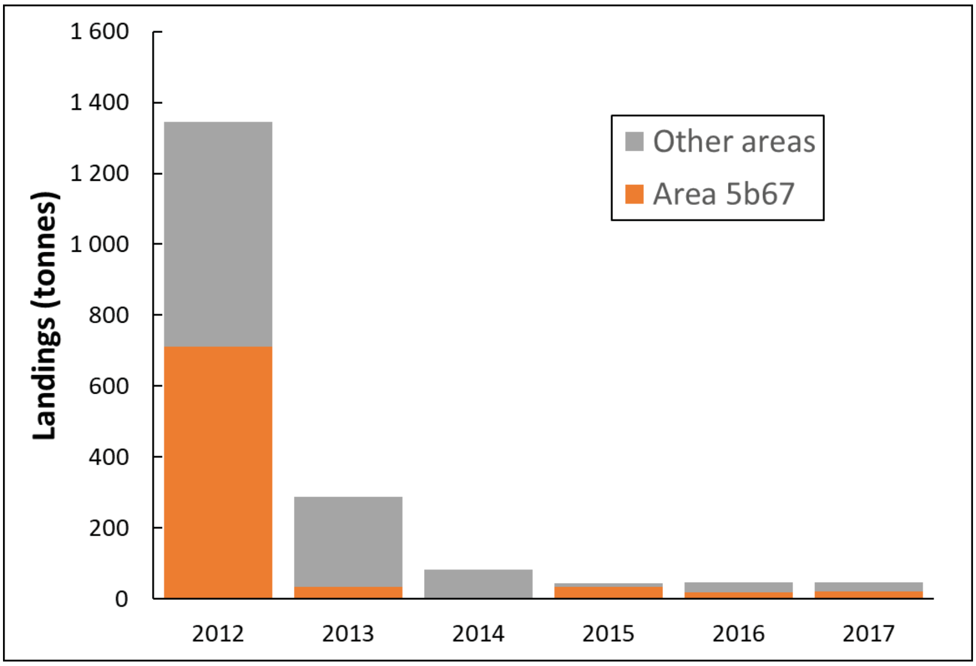
Deep trawl fisheries of the Rockall Plateau and Trough

Blue ling deep trawl fishery

Deep commercial trawling in the high seas started on Hatton Bank and Lousy Bank around the Rockall Plateau in the mid-1970s, with German and French trawlers targeting seasonal spawning aggregations of blue ling along the continental margin at depths of 500–600 m (Ehrich and Reinsch, 1985, Charuau *et al*., 1995; Gordon, 2001; Allain *et al.*, 2003; Large *et al*., 2003). Landings rose after 1978, reaching 9 400 tonnes in 1980. From 1988, the fishery extended to the Hatton Bank aggregation, which yielded a peak landing of 3 300 tonnes in 1993, though catches declined soon after. Catches increased again at the turn of the century, primarily driven by Scottish effort, peaking at 4 000 tonnes in 1999. Landings declined to low levels after 2006.

Catches in the high seas portion for the short time series available were highest in 2012, at over 1 300 tonnes, which includes a significant proportion coming from Area 12b. Thereafter catches in the high seas were much lower, owing to reduced fishing effort (Figure 5.13).

FIGURE 5.13
Landings of blue ling from the high seas portion of Hatton and Rockall Banks



The "Other areas" catch is attributable to the western Hatton Bank.
Source: ICES 2015; ICES WGDEEP, 2016, 2017, 2018.

Blue ling is assessed by ICES for Area 5b67 as a single stock. Fishing pressure peaked sharply in the early 2000s and has declined since due to stricter TACs. ICES advised no directed fishing in response to unacceptable stock declines for 2003–2012 and then gradually increased an allowable annual catch from 3 900 tonnes in 2013 to the current advice of no more than 10 800 tonnes. Twenty percent of this stock was caught in the high seas in 2012, but this declined to around one percent for 2013–2017; almost all fishing therefore took place within EEZs. The European Union have had a TAC on this stock since at least 2003 (of 1 717–5 046 tonnes, depending on their perceived state of the stock). Owing to the typically small catches in the high seas, NEAFC has no specific management measure for the blue ling stock, but maintains a seasonal closure in a known spawning area.

Roundnose grenadier deep trawl fishery

During 1976–1977, the trawler fleets of the former USSR fished for roundnose grenadier on the slopes in the Rockall Trough, on the banks between the Rockall and Faroe plateaus, and on Hatton Bank (where they were in the modern high seas) (Gordon, 2006; Lorance *et al.*, 2008; Shibanov and Vinnichenko, 2008). The extensions of national jurisdictions in 1977 ended that fishing but Russian Federation trawlers returned to the deep slopes of Rockall Bank after the contraction of British jurisdiction in 1997, taking argentine, blue ling, roundnose grenadier, tusk and chimaeras (Gordon, 2006; Shibanov and Vinnichenko, 2008).

Roundnose grenadier was also caught by vessels from France, Faroe Islands, Spain and others, mainly from EEZ waters around the Faroe Islands and on the eastern side of the Rockall Trough at depths of 600–1 200 m, beginning in 1989 (Gordon, 2006).

The Spanish fleet, from 1996 and especially after British jurisdiction contracted the following year, developed a more lasting fishery, working mainly on the western part of Hatton Bank, as well as two small banks called Fangorn and Lorien, near the deep, southwestern end of the Rockall Plateau, at depths of 800–1 600 m (mostly 1 000–1 400 m).

Spanish landings of roundnose grenadier from Area 12b, which broadly corresponds with their high seas fishery, rose from 1 100 tonnes in 1996 to a peak of nearly 12 000 tonnes in 2003; they remained high until 2007, after which TAC restrictions led to a decline. The fishery began with five vessels, but the fleet increased to 24 vessels by 2000, though the maximum in any one month that year was 13 vessels. By 2005, 25–28 vessels were involved, all fishing out of Galician ports. Over the 1996–2000 period, annual effort grew from 352 to 1 363 fishing days. The fishing was spread throughout the year but the peak season was June to September. The vessels used through to 2000 had been built between the mid-1970s and late-1980s. They were between 46–84 m overall, 264–1 866 GRT, the smaller ones opening the fishery and the larger following. Two pair trawlers worked in the fishery in 2000, but the rest of the fleet was made up of stern trawlers.

French trips observed in 1995–1997 targeted roundnose grenadier, with black scabbardfish, siki sharks, orange roughy, blue ling and common mora also caught at various depths and landed (Gordon, 2001; Large *et al.*, 2003; Holley and Marchal, 2004). Slickheads and smaller roundnose grenadier were discarded. The discard rate increased with depth: 25 percent at 800 m depth to 61 percent at 1 200 m. Preliminary estimates of total discards by French deepwater fishing alone were about 20 000 tonnes annually (Allain *et al.*, 2003). A total of 11 French trawlers caught a total of 713 tonnes of roundnose grenadier in the high seas area of the Rockall Plateau in 2005, though the following year that catch was down to 184 tonnes (Bensch *et al.*, 2009).

The current bottom trawl fisheries in the high seas on the Rockall Plateau (and the adjacent international portion of Lousy bank) are likewise much reduced from what they once were. French trawlers caught roundnose grenadier in a multispecies deepwater fishery, whereas Spanish trawlers operated further offshore along the western slope of the Hatton Bank. Total landings in the high seas portion of the Rockall/Hatton Bank roundnose grenadier stock in this short time series were highest in 2012 at 8 579 tonnes, before dropping suddenly to an average of 1 412 tonnes per annum, without no obvious trend. The trend in landings for the entire stock in Area 5b12b67 shows a decline from around 10 000 tonnes in 2005–2007 to around 1 500 tonnes in 2015–2017 (Figure 5.14). Assessments indicate that the biomass is low but recovering (ICES WGDEEP, 2018). Landings from the high seas in 2016 were 923 tonnes.

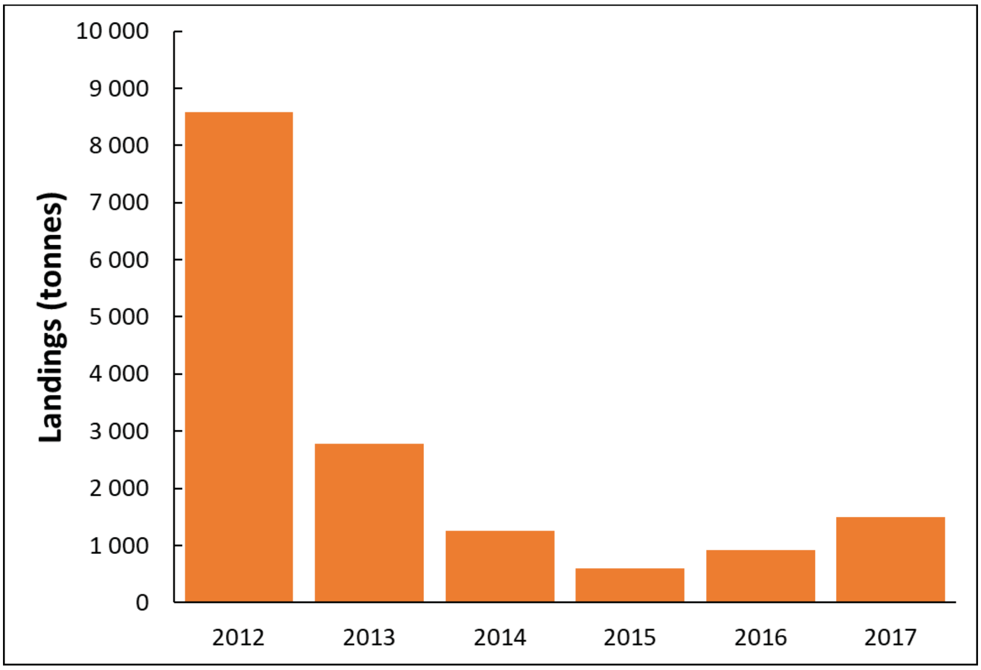
The roundnose grenadier fishery in Area Vb6712b is assessed as a single unit by ICES, though it provides catch options for Area 12b separately. Some 70 percent of the catch of this stock comes from the high seas and thus represents a substantial fishery. NEAFC set TACs for Areas 5b1a and 6bi7ciki12b for 2016 (2000 tonnes and 796 tonnes), 2017 (1157 tonnes and 526 tonnes) and 2018 (1170 tonnes and 526 tonnes) respectively. The European Union has set its own TAC for this stock since at least 2011 and has not accepted the TAC set by NEAFC.

Slickhead deep trawl fishery

While the fishery primarily targeted roundnose grenadier, it also took considerable quantities of Baird's slickhead (=Baird's smoothhead). Area 12 landings, which seem to have been made primarily by Spanish vessels fishing on Rockall Plateau, rose from 230 tonnes in 1996 to over 12 500 tonnes in 2002, but then declined swiftly. Some 1 800 tonnes were landed in 2007 but subsequent management restrictions caused a further decline and 421 tonnes were landed in 2016 (ICES WGDEEP, 2016, 2018).

During 2004–2006, the Spanish wetfish bottom-trawl fishery operated primarily on Hatton Bank, primarily targeting slickhead followed by grenadiers, with respective landings of 53 percent and 40 percent by weight (Punzón *et al.,* 2011). Slickheads had been taken in the Rockall Trough fisheries, often in considerable quantities, but had been routinely discarded because the high water content made them unpalatable (Gordon, 2006). How the Spanish created a marketable product from them is not

FIGURE 5.14
Landings of roundnose grenadier from the high seas portion of Hatton and Rockall Banks



Source: ICES 2015; WG DEEP, 2018.

immediately obvious. The fishery also took black scabbardfish, though usually less than 250 tonnes per year (ICES WGDEEP, 2016).

Baird's slickhead is included in the ICES catch database and it seems that a substantial proportion of the catch may come from the high seas areas around Rockall. This species is not assessed by ICES, nor are there any specific NEAFC measures.

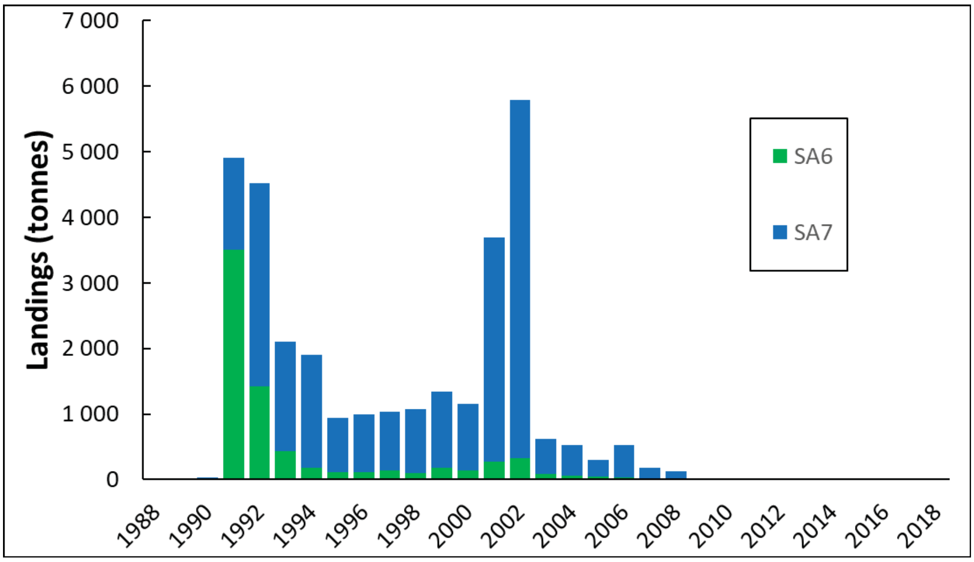
Orange roughy deep trawl fishery

In 1991, the expanding French fishery found commercial concentrations of orange roughy, and developed a specialized industry based on New Zealand's success, mostly taken from seamounts within EEZs at depths down to 1 800 m (Gordon, 2001, 2003, 2006; Lorance and Dupouy, 2001; Large *et al.*, 2003). Catches in Area 6, mostly within the EEZ, peaked at 3 500 tonnes in the first year but declined to minimal levels within two years. The French largely left the fishery at the end of the 1990s, and targeted fishing ceased in 2006. Orange roughy were taken from the high seas portion of Rockall Plateau only in rather insignificant numbers as bycatch. Around 2001, after the collapse of the fishery in Area 6, a fishery emerged in Area 7 comprising of mostly Irish vessels, and catches rose sharply by 2002. Strict European Union TACs from 2003 led to a major decline in catches and a cessation of the fishery in 2008 (Figure 5.15). It is likely that most of these catches came from within EEZs. No catches have been reported from these two areas since 2009.

ICES has been advising for no directed fishery and keeping bycatch in mixed fisheries as low as possible since 2003.

A TAC of 88 tonnes was introduced by the European Union for Area 6 in 2003, which was maintained until 2009 when it was reduced to 15 tonnes. It was then reduced each year, reaching zero from 2010 (ICES WGDEEP, 2018) which brought the directed fishery to an end. The Area 7 TAC, also introduced in 2003, was much higher, at 1 349 tonnes, and was not severely reduced until 2007. It too was set to zero from 2010 (ICES WGDEEP, 2018).

FIGURE 5.15
Landings of orange roughy from ICES subareas 6 and 7, probably almost all within EEZs



Source: ICES WGDEEP, 2018.

In 2007 NEAFC introduced a measure prohibiting fishing for orange roughy until further information on stock status became available. NEAFC banned directed fishing in 2008, 2010, 2011, 2013, 2014 and 2016, as evidence suggested that stocks were severely depleted. No agreement could be reached on suitable measures for NEAFC to adopt in 2017 and 2018. The NEAFC measures, when adopted, essentially only apply to orange roughy fisheries in the high seas outside Area 67, i.e. primarily on the Mid-Atlantic Ridge (Area 10).

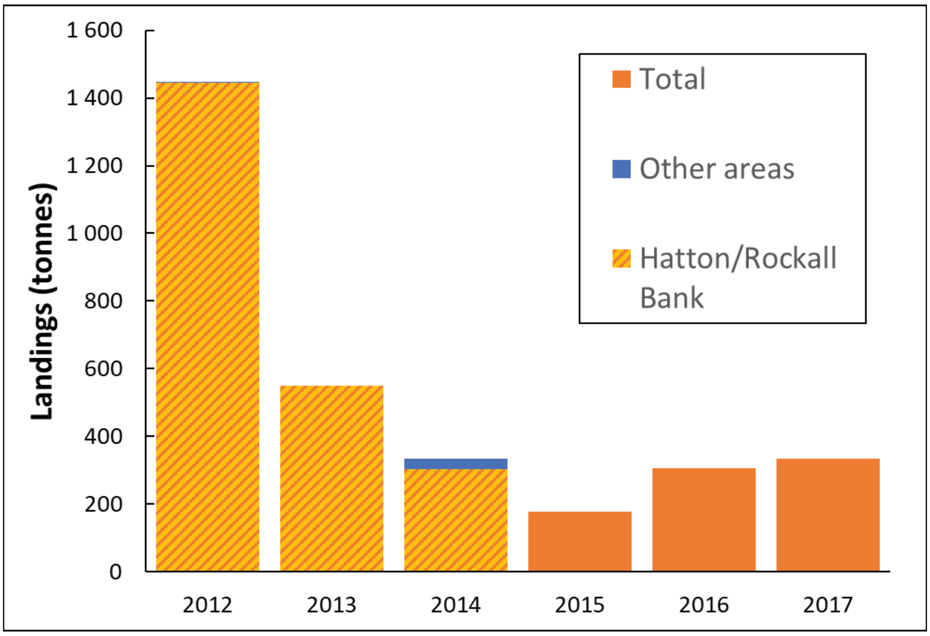
Minor deep trawl fisheries

From 1989, the French industry expanded its deepwater operations, driven by reductions in the TACs for saithe, which had been a principal target for French trawlers (Holley and Marchal, 2004). The industry was assisted by EU financial support through an “Exploratory Fishing Voyage” scheme and ran a successful marketing initiative promoting novel products (McCormick, 1995; Gordon, 2001; Large *et al*., 2003). Scottish trawlers also developed a fishery for monkfish – perhaps because they were not able to work at the great depths where other resources were available (Gordon 2001, 2006; Gordon *et al*., 2003). In 2006, four Scottish trawlers targeted monkfish on Rockall Plateau, at depths down to 800 m, their bycatches including ling, blue ling and deepwater sharks (Bensch *et al*., 2009).

Other minor fisheries targeted saithe and black scabbardfish. Some of the effort continues to be targeted on black scabbardfish using mainly bottom trawls in this high seas area, while each target species is also taken as bycatch when targeting the other, as is blue ling, though directed fishing on the blue ling aggregation on Hatton Bank has ended (ICES WGDEEP, 2016). Most of the black scabbardfish catches come from this area, with over 1 400 tonnes recorded in 2012, dropping to around 200–500 tonnes annually for 2013–2017 (Figure 5.16).

Currently, there is only a very small bycatch of deepwater sharks, which were represented only by longnose velvet dogfish. At lesser depths some haddock trawling continues, mainly by Russian Federation vessels, though the fishery only takes a small fraction of the catches it once achieved, and with some tusk as bycatch. Data for 2014 are not available but 31 and 142 tonnes of haddock were taken from the high

FIGURE 5.16
Landings of black scabbardfish from the high seas portion of Hatton and Rockall Banks



The total catches are likely to be almost entirely from the Rockall/Hatton Bank area, with minor contributions from the MAR.
Source: ICES 2015; ICES WGDEEP, 2018.

seas portion of the Plateau in 2012 and 2013 respectively (ICES, 2015). Some of these fisheries are assessed by ICES when they are more significant within EEZ waters; of these, perhaps monkfish and black scabbardfish are the most noteworthy.

Since the activity mostly happens inside EEZs, NEAFC does not have any specific measures on these fisheries and target species, but does have some important relevant general measures, especially relating to the protection of bycatch species. Directed fisheries in the NEAFC regulatory area for spurdog in 2017 and 2018, and for specified species of deep-sea chimaeras, deep-sea rays, and deep-sea sharks, have been prohibited. Furthermore, through measures relating to the protection of VMEs and deep-sea fisheries, NEAFC has controlled the expansion of bottom fisheries in new areas and for new targeted species (NEAFC Rec. 19:2014; 11, 12, 13:2017; 7:2018).

Longline fisheries on Rockall

Shetland fishermen took Atlantic cod around the shoal waters of the islet of Rockall using handlines from the early nineteenth century, and there was a substantial fishery from 1865–1914. English steam liners fished off Iceland and around Rockall from 1889, catching ling, Atlantic halibut and other species, some of which potentially fell in the modern high seas. Scottish and Faroese liners replaced English liners through the twentieth century and continued to fish on the Rockall Plateau, taking primarily ling (Blacker, 1982; Newton *et al.*, 2008).

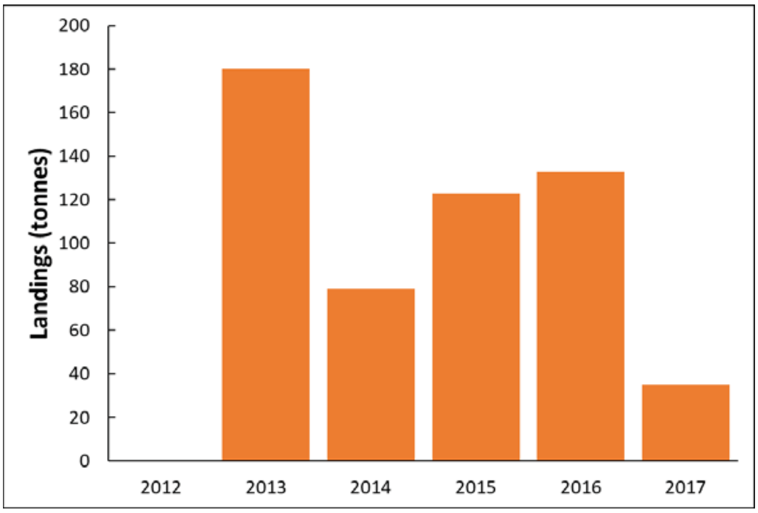
The Norwegian longline industry expanded to western grounds around the Shetlands and Faroe Islands after the introduction of steam power around 1900, fishing firstly for Atlantic halibut, and then ling and tusk as halibut catch rates fell. After the disruption of 1939–1945, larger motorized longliners were built, which allowed further expansion to the grounds west of Ireland and on the Rockall Plateau – the latter including fishing in the modern high seas (Bergstad and Hareide, 1996). New and increasingly large vessels equipped with autoline systems joined the Norwegian fleet from the late 1970s and continued to fish the western grounds, including the Rockall Plateau, taking primarily ling and tusk (Bergstad and Hareide, 1996; Gordon *et al.*, 2003), but also greater forkbeard, blue ling and skates. Some of these experiments specifically targeted international waters and non-traditional resources but those efforts did not result in lasting commercial fisheries. There were 12 longline vessels active in 2003, but this reduced to 2–7 during 2004–2016 (Bensch *et al*., 2009, NEACF DSS, 2017). They targeted ling and tusk on Rockall Bank at 200–600 m depth, or else Greenland halibut and deepwater sharks on the slopes of Hatton Bank, at depths down to 1 700 m. The Norwegian longline fishery caught around 600 tonnes of ling in 2007, 2009 and 2010, and now continues at a reduced level in the high seas area of Rockall Bank with landings of ling stable at 100–150 tonnes per year, supplemented by some 20–40 tonnes of tusk annually (Figure 5.17; NEAFC DSS, 2017).

A Spanish longline fishery emerged from 1991, taking deepwater sharks on grounds from the Celtic Sea to Rockall, with a varied bycatch that was sometimes landed. By 2004–2006, separate fisheries had developed for hake, ling, conger and forkbeards. It is unclear how much if any was in the high seas (Castro *et al*., 2011; Punzón *et al*., 2011).

The Faroe Islands have also fished with longlines in the high seas around Hatton and Lousy Banks with rather irregular effort involving 2–3 vessels since 2005 with 16–87 days of effort per year for the 9 years fished during this period (NEAFC DSS, 2017). This fishery likely targeted blue ling.

Reported landings of ling (all flags and all gears combined, though primarily taken by Norwegian longlining) from Area 7b, including the high seas portion, reached 3 743 tonnes in 1989 and have been stable at 533–2 687 tonnes since with no obvious trend. Annual tusk landings from Area 7b have usually been less than 1 000 tonnes but reached a peak of 2 344 tonnes in 2000 (ICES WGDEEP, 2017). Catches from the high seas portion for 2012–2017 have been low and sporadic, representing less than one percent of the catch within the adjacent EEZ waters (ICES, 2015; ICES WGDEEP, 2017, 2018). There is also some longlining for blue ling on Lousy Bank. These fisheries are assessed by ICES, but given that they are similar to many of the above fisheries, the catch is predominantly in the EEZs.

FIGURE 5.17
Landings of ling from the high seas of the Atlantic Ocean



Source: ICES 2015; ICES WGDEEP, 2018.

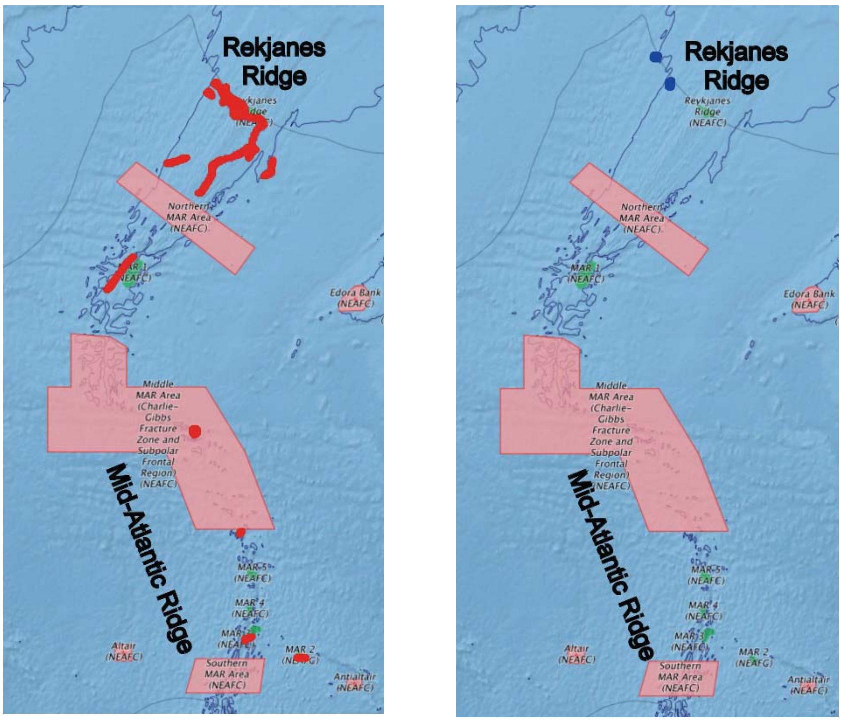
Gillnet and pot fisheries of the Rockall Plateau and Trough

From 1994 onwards, up to 50 gillnetters, Spanish-owned but registered in other European Union Member States (and some in other states, including Panama), fished along the shelf break at 100–600 m depth, from Porcupine Bank to as far north as the Rockall Trough. The fishery diversified in the 2000s, to take monkfish and ling at 100–900 m depth, red crab at 600–1 200 m and deepwater sharks at 800–1 600 m. These fisheries were mostly in waters under national jurisdiction, but extended into the high seas slopes of Rockall and Hatton Banks. In the latter area, the target species were monkfish at 500–900 m depth and “siki sharks” at depths of more than 800 m. Declines in catch rate made the fishery unprofitable and half the fleet moved to Brazilian waters in 2000–2001. By 2005, there were around 12 British and 4 German vessels. In 2006, concerns about lost gillnets and ghost-fishing resulted in a high seas ban by the European Union and NEAFC for gillnets and tangle nets set below 200 m. This presumably ended the high seas monkfish fishery. There appears to have been no gillnetting on the high seas portion of the Rockall Plateau in the past decade as a result (Gerritsen and Lordan, 2014).

Potting for crab occurred during 2008–2012, on the slope of the Plateau, apparently straddling the Irish EEZ and the high seas (Gerritsen and Lordan, 2014), but it is not known if this currently continues in the high seas.

FIGURE 5.18

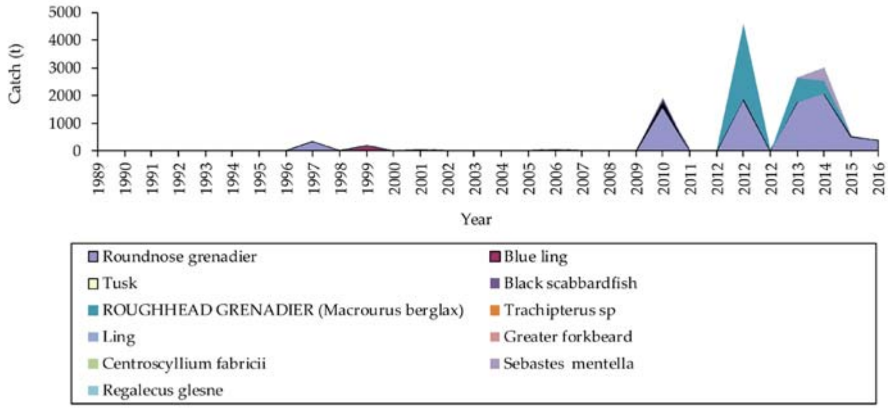
Composite map showing approximate areas for bottom fishing on and around MAR during 2014–2016 for: (a) bottom trawling (solid red), and (b) static gears, mostly longlines (solid dark blue), occurring within the existing fishing areas (green)



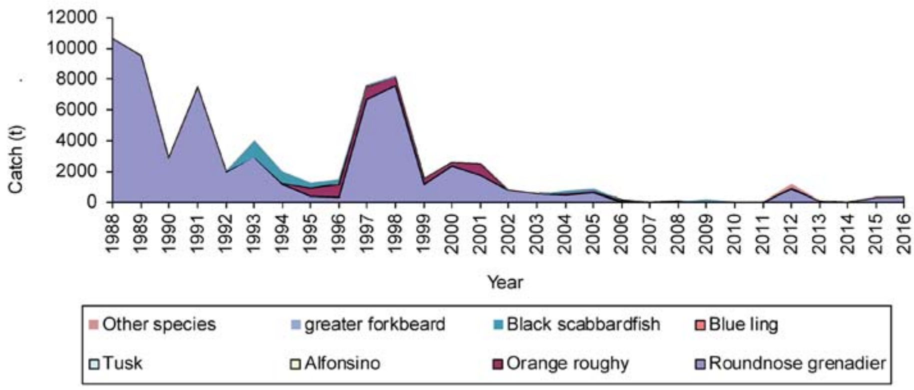
(a) (b)

The occasional bottom trawl fishing seen within the VMEs (light red) occurred prior to adoption of the VME closure.
Source: ICES WGDEEP (2013–2017); the original maps are available on the ICES website.

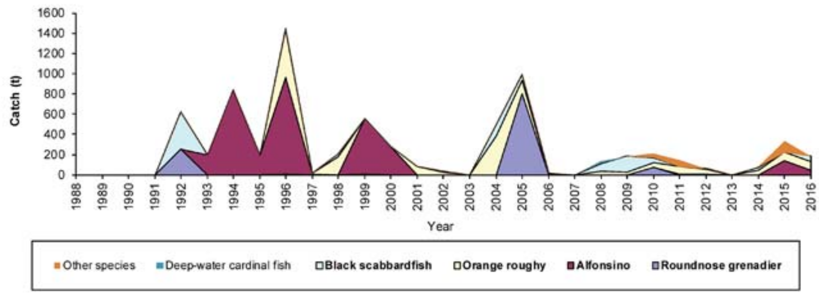
FIGURE 5.19
Catches (tonnes) of various species along the (a) northern, (b) central and (c) southern portions of the high seas part of the Mid-Atlantic Ridge



(a) Northern MAR – ICES area 14b1



(b) Central MAR – ICES areas 12c and 12a1



(c) Southern MAR – ICES area 10b

Source: ICES WGDEEP, 2017.

Mid-Atlantic Ridge fisheries

There have been a variety of specialized fisheries operating along the high seas portion of the MAR using trawls and longlines (Figure 5.18 and Figure 5.19).

Grenadier trawl fishery

The MAR roundnose grenadier stock straddles the Icelandic EEZ and high seas boundary, occupying mainly ICES high seas Areas 14b1, 12a1, 12c and 10b. Roughhead grenadier is known to occur mainly north of 60° N. The grenadier fisheries have officially been reported as a mix of roundnose grenadier, roughhead grenadier, and to a lesser extent roughsnout grenadier, though there is suspected misidentification of most of the two species. References to "grenadier" below refer to the above three reported species combined, though most are likely to be roundnose grenadier (ICES WGDEEP, 2017). There are at least 16 species of grenadiers inhabiting the MAR (Bergstad *et al*., 2008).

Most of the grenadier catches along the MAR are taken by midwater trawls with a smaller but unknown fraction taken by bottom trawls. The fishery started in 1973 when the former USSR found the resource on multiple seamounts associated with the MAR, but it was not fished by other countries until 1990 when Poland, Latvia and the Faroe Islands joined for the rest of the 1990s and into the early 2000s. Since the large catch reduction by the Russian Federation fishery in 2006, Spain is the only country to have a significant grenadier fishery on the high seas portion of the MAR up to the present day, typically employing a bentho-pelagic trawl (Figure 5.20a). Total landings throughout the high seas MAR rapidly increased from the initial fishery in 1973 and peaked at nearly 30 000 tonnes in 1975; however, these declined to produce average annual landings of a little over 10 000 tonnes during the 1976–1989 period. Annual catches from 1990 to 2016 averaged almost 3 000 tonnes, with higher catches in 1997–1998 due to a Polish fishery, and in 2011–2014 due to a Spanish fishery. Grenadier catches have averaged 2 500 tonnes per year, though with a considerable annual fluctuation of 494–7 134 tonnes depending on the interest in the fishery (Figure 5.20b). Published sources and ICES reviews document the history of high seas grenadier fisheries (Clark *et al*., 2007; Vinnichenko and Kakora, 2008; ICES WGDEEP, 2016). The Russian Federation fleet substantially reduced its effort in 1992–1996, and since then the Spanish fishery has been the more significant.

The MAR roundnose grenadier fishery is one of the few that is exclusively within the high seas, and with the possible exception of snow crab in the Barents Sea "Loophole", is the biggest deep-sea fishery in the NEAFC regulatory area. Catches showed marked decreases around the mid-1990s and, although the reports are not readily available, ICES advised that the fishery should not be allowed to expand for 2003–2012. From 2011, the advice also asked for catch reductions to be considered; this was cemented in 2013–2014 when a 20 percent reduction and a TAC of no more than 1 350 tonnes was recommended. The recommended TAC was further reduced to no more than 717 tonnes for 2015–2019.

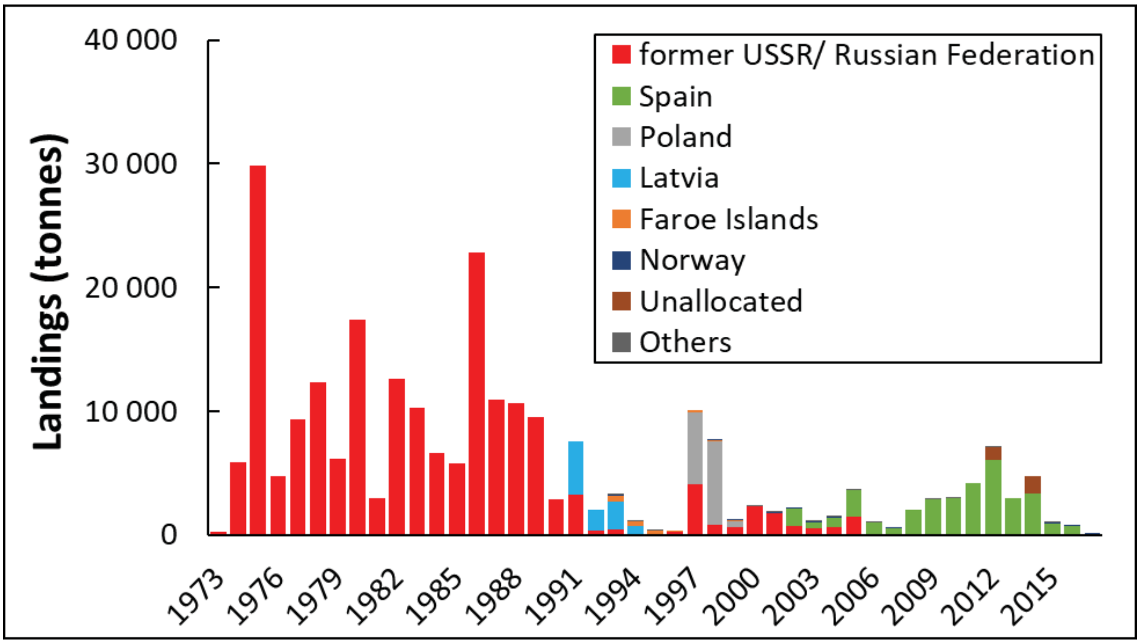
NEAFC first adopted TAC measures for roundnose grenadier on the MAR in 2014; initially set at 1 350 tonnes, in 2015 it was basically split into 717 tonnes of roundnose grenadier and 900 tonnes of roughhead grenadier. Continued concerns reflected in the ICES advice statements led NEAFC to adopt a TAC of 717 tonnes for roundnose grenadier for each year in the 2016–2018 period and close directed fisheries for roughhead and roughsnout grenadiers. Bycatch of these and other grenadiers should be counted against the TAC for roundnose grenadier. The European Union objected to these measures, as it sets independent TACs applicable to grenadiers on the MAR.

Blue ling trawl and longline fishery

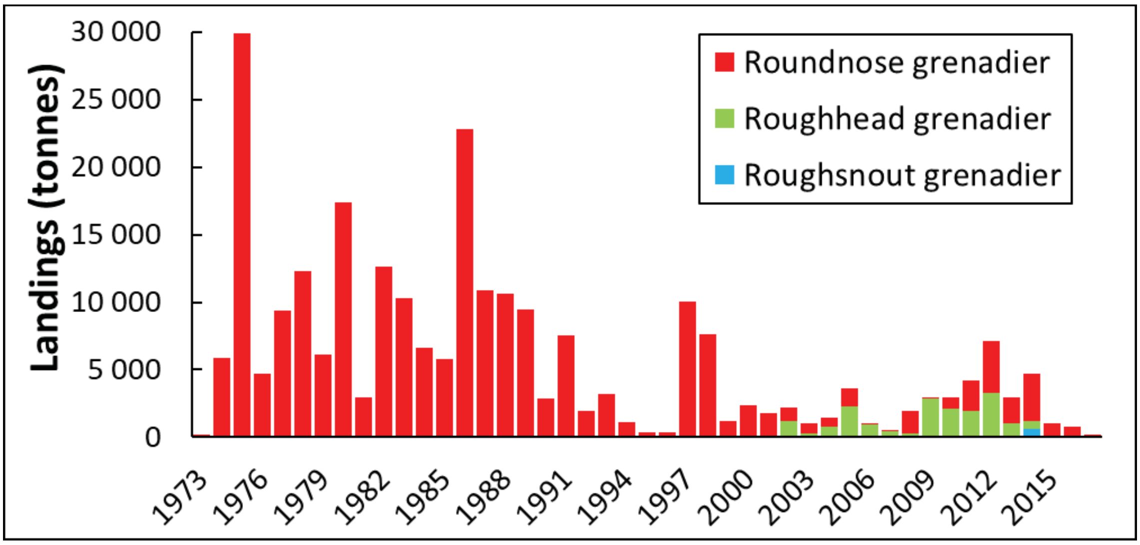
The MAR blue ling fishery is essentially within the EEZs of Iceland and Greenland. Catches are primarily taken with bottom trawls. ICES (2015a) reports no blue ling catches for the high seas portion of the MAR for 2012 and 2013. One known spawning concentration is on the east side of the MAR and straddles the boundary of Iceland's EEZ, (Magnússon, 1998). The high seas portion of the known aggregation site was closed by NEAFC during spawning seasons from 2010 (Figure 5.12)[2]. It is unlikely that there are currently any significant blue ling catches in the high seas part of the MAR. ICES assesses blue ling on the East Greenland and Iceland grounds and there are national measures within the EEZs.

[2] NEAFC Recommendation X:2010.

FIGURE 5.20
Officially reported grenadier landings on the high seas Mid-Atlantic Ridge for 1973–2017 by (a) country, and (b) species



(a)



(b)

See text for discussion on misreporting of species.
Source: ICES WGDEEP, 2018.

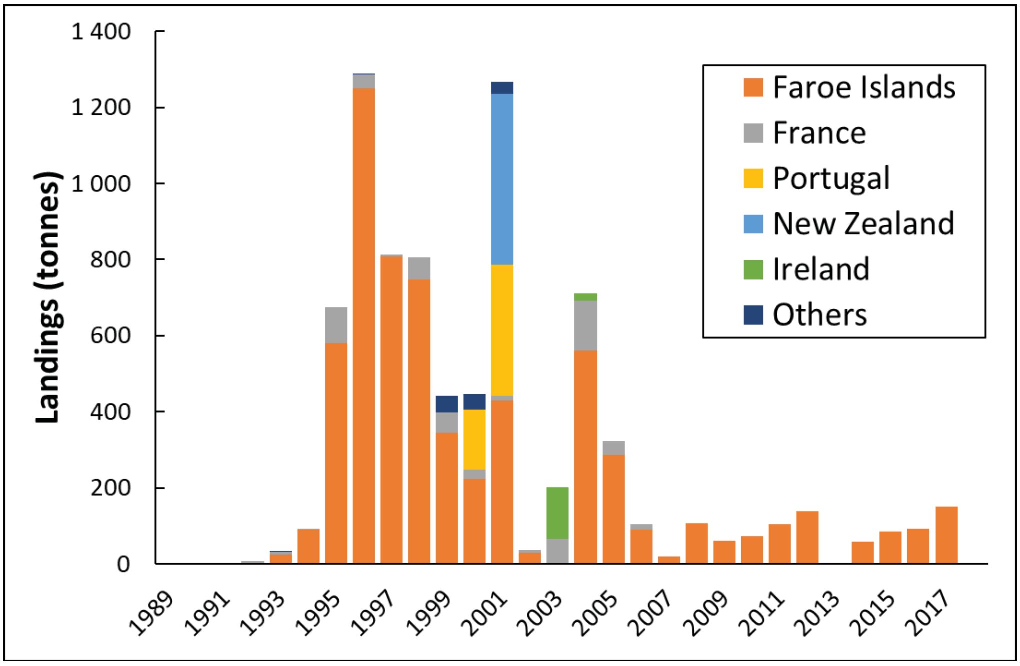
Orange roughy bottom trawl fishery

The commencement of the orange roughy fishery in the Rockall Trough in 1991 encouraged exploration on the MAR, including on the Reykjanes Ridge. Vessels from several nations were involved, some with support from their flag states, and the focus was not only on orange roughy but also alfonsino, grenadiers, common mora, wreckfish and sharks, with longline as well as trawl gears used. Reports on some of those explorations have been published by Hareide and Garnes (2001). The most persistent fisheries to emerge from that experience was by bottom trawlers from the Faroe Islands, which may have trawled for roughy on Hatton Bank during 1992–1994, before turning to the resource on the MAR (Gordon, 2006). They have fished on the MAR from 1994 and continued sporadically until the present day, accounting for 80 percent of the total orange roughy catch from the high seas MAR in this period (ICES WGDEEP, 2016). The Faroe Islands' annual catch peaked at almost 1 300 tonnes in 1996 and averaged 480 tonnes between 1995–2005; thereafter it was lower, averaging 75 tonnes per year up to 2016. France also had a fishery from 1992 to 2006, albeit with smaller catches averaging only 38 tonnes per year. New Zealand fished for a single year in 2001 and caught 450 tonnes from Area 12. Portugal are reported to have caught 157 tonnes and 343 tonnes in 2000 and 2001 from Area 10, though this may have been within their Azores EEZ (Figure 5.21). Around 70 percent of the total high seas MAR catch has been from Area 12, though since 2010 more has been taken in Area 10 to the south.

The Faroe Islands are the only country to have fished regularly for orange roughy on the high seas MAR since around 2005 and continued with a single vessel for 2014–2016 (Ofstad, 2016). The roughy were mainly caught on a seamount north of the Azores (Area 10) and a lesser quantity from south of Hatton Bank (Area 12). The trawl used is based on a New Zealand design and is fished for only 10–20 minutes with the net touching the sea floor and the otter doors staying above bottom (Thomsen, 1998).

ICES has always expressed concern over the fishing of orange roughy at anything above very low exploitation rates, though there is not enough information for an assessment. In 2003 and 2004 ICES requested strict limits on exploitation and close monitoring of populations. They have since advised no directed fishery and to keep bycatch as low as possible. This was strengthened from 2011, when ICES advised that measures be adopted to minimize bycatch. The management of the orange roughy

FIGURE 5.21
Orange roughy landings of on the high seas Mid-Atlantic Ridge (ICES Subareas 10 and 12) by country



Others include England and Wales, Spain, Russian Federation, Iceland and Norway.
Source: ICES WGDEEP, 2018.

fishery has always been contentious in NEAFC, and this is reflected in the history of measures adopted. NEAFC prohibited fishing for orange roughy in 2007, though this was relaxed in 2008, 2010, 2011, 2013 and 2014, and fishing was permitted by NEAFC contracting parties with a previous fishing history and a catch limit of 150 tonnes per contracting party. NEAFC prohibited directed fishing for orange roughy in 2016. Moreover, though it was discussed, NEAFC did not adopt management measures for 2009, 2012, and 2017 onwards. The European Union has had a zero TAC for orange roughy since 2010.

Tusk gillnet and longline fishery

Tusk is a secondary target species in longline fisheries and bycatch in trawl and gillnet fisheries throughout the northeast Atlantic. It is however usually a minor species on the MAR. Longliners from the former USSR fished for tusk during 1983–1987, working on 20 seamounts on the Ridge between 57° N and 51° N (Clark *et al*., 2007; Vinnichenko and Kakora, 2008). Since 1993, vessels for the Faroe Islands (1993–1997), Norway (1996–2004) and the Russian Federation (2004–2007) have taken small catches, normally totalling less than 30 tonnes per year, with a peak annual catch of 158 tonnes in 1996. There have been virtually no catches of tusk since 2008 (ICES WGDEEP, 2017).

Giant redfish longline fishery

In March 1996, during the explorations for other species, a resource of "giant redfish" was discovered on the MAR, immediately outside the Icelandic EEZ (Hareide and Garnes, 2001)[3]. A small fishery developed, mostly deploying specially developed vertical longlines set on the summits of seamounts or coral banks, and generally close to the limit of Icelandic jurisdiction – though including some seamounts as far south as 54° N. Over a total of 293 fishing days during 1996–1997, 12 Norwegian longliners harvested 1 000 tonnes of redfish – most of it in July and August 1996. There was some additional fishing by Icelandic vessels (Johansen *et al*., 2000; Hareide *et al*., 2001) but the fishery did not persist. A similar fishery was undertaken by the Russian Federation longliners, in 2005–2007: the catch during the first two of those years amounted to 400 tonnes, and was attempted again in 2009 (Vinnichenko and Kakora, 2008; ICES WGDEEP, 2017).

Alfonsino trawl fishery

In the mid-1970s, the expanding fisheries of the former USSR began targeting alfonsino on subtropical seamounts, and one of the locations was the seamounts north of the Portuguese EEZ around the Azores (Vinnichenko, 1998; Vinnichenko and Kakora, 2008). A total of 1 800 tonnes was taken during 1978–1979, and annual catches were subsequently 195–960 tonnes for the period 1995–2000, after which the fishery ceased. The alfonsino was apparently mostly harvested by aimed midwater trawling by the former USSR and subsequently the Russian Federation (Clark *et al*., 2007; Vinnichenko and Kakora, 2008). However, the 1993 catch was by Norway in an exploratory fishing trip, all of it in Area 10b (ICES WGDEEP, 2017). Since 2000 only a few tonnes have been recorded each year in the NEAFC regulatory area, but Faroe Islands bycatch of 141 tonnes in 2015 and 48 tonnes in 2016 were reported from Area 10b. A few hundreds of tonnes of alfonsino are still being caught in the EEZs of Portugal, Spain and France (ICES WGDEEP, 2017). Trawl gears are banned in the Azores EEZ and catches there are taken with longlines.

ICES assess alfonsino in the northeast Atlantic as a single unit in FAO Major Fishing Area 27 (EEZs and high seas) and generally advises that the fishery should

[3] A form that morphologically resembles Sebastes norvegicus (the species often erroneously named *S. marinus*) but is genetically more similar to *S. mentella* (Johansen *et al*., 2000).

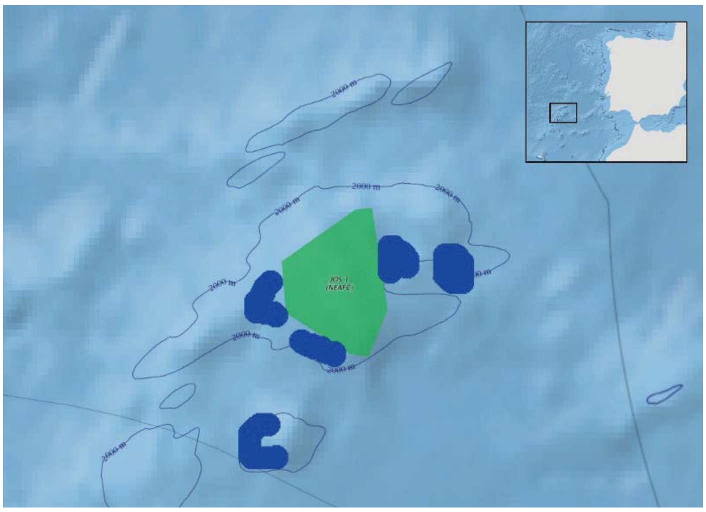
not be allowed to expand until further information is available to show the fishery is sustainable. The TAC advice for the entire northeast Atlantic should be no more than 280 tonnes for 2017 and 2018. Almost no catch of alfonsino was recorded in the high seas during 2012–2014 (Table 5.4). However, the potential exists for a high seas fishery in Area 10b and for the years 1993–2000 and 2015–2016 this area accounted for more than half of the northeast Atlantic catches. NEAFC does not have any management measures for alfonsino but is aware of the potential for rapidly expanding fisheries for this aggregating seamount species and may introduce measures should this happen. The European Union has a TAC in line with the ICES advice, which applies to its own vessels fishing inside and outside the EEZs.

Fisheries on isolated seamounts

Little is known of fishing on the seamounts which dot the northeast Atlantic away from the MAR. The former USSR began a fishery on the seamounts of the Madeira–Canaries area in 1970, primarily using midwater trawls to take pelagic species, though there was some bottom trawling and some targeting of silver scabbardfish. Most of the fished seamounts later fell within the EEZs around the islands; of the two which remained in the high seas, Ampere Seamount lies at 35° 05' N, hence outside the northeast Atlantic region. Of the Madeira–Canaries seamounts, only Josephine Seamount (at 36° 40' N 14° 15' W) remains in the northeast Atlantic high seas. The fishery there ceased in the 1980s but resumed at a low level in the 1990s (Clark *et al*., 2007; Vinnichenko and Kakora, 2008). The Josephine Seamount is the only off-MAR seamount classified by NEAFC as an 'existing fishing area' – essentially based on the reporting of fishing there in the 1987–2007 reference period. Recent set longline fishing activities have been reported on and around Josephine seamount, though the target species is unknown and they could be midwater for large pelagic species (Figure 5.22; ICES WGDEC, 2015).

NEAFC does not have any specific management measures for these isolated seamounts, but many lie in 'new fishing areas' where only exploratory fishing with bottom-touching gears is permitted following authorization from the commission. No such authorizations have ever been applied for, or granted. The Altair and Antialtair seamounts are closed to fishing, but despite that ICES has recommended a VME closure

FIGURE 5.22
Records of longline fishing at Josephine seamount in 2014.
The NEAFC "existing fishing area" is shown in green



Source: ICES WGDEC, 2015. Note that the above image has been redrawn for the purposes of the present review.

in that area, the Josephine seamount remains an 'existing fishing area' essentially open to bottom fisheries. Fishing for deep-sea species on seamounts using midwater gear is regulated by species-specific regulations and the general deep-sea fisheries measures maintained by NEAFC.

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6. Northwest Atlantic Ocean

FAO Major Fishing Area 21

SUMMARY

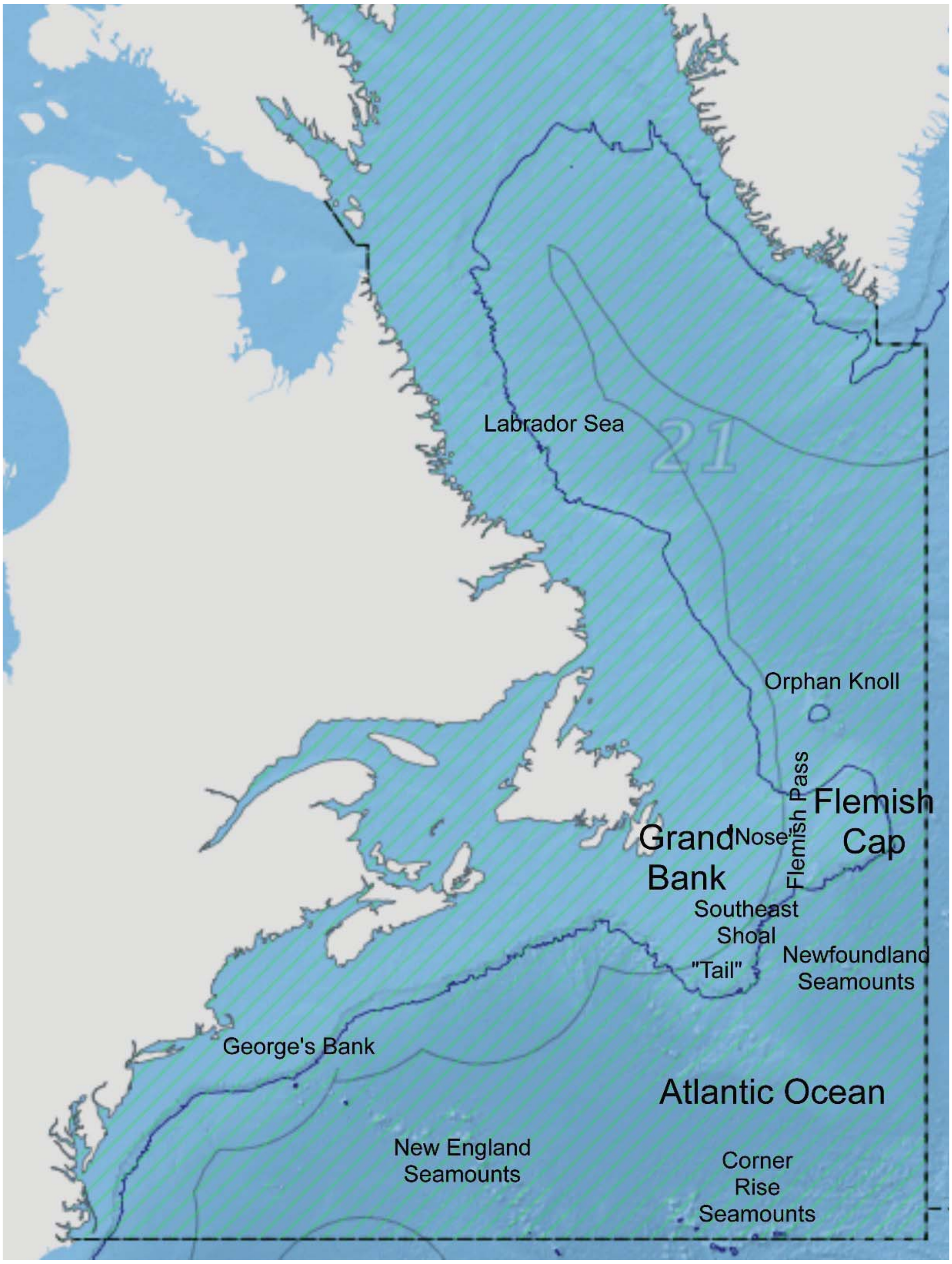
Bottom fishing in what are now the high seas began in the northwest Atlantic and continued there for centuries before commencing in other regions (Figure 6.1). Most subsequent innovations in high seas bottom fisheries first appeared in the northwest Atlantic, subsequently spreading elsewhere. Stocks of the region's principal resources, such as Atlantic cod, redfish, American Plaice, yellowtail flounder, and witch flounder, are currently rebuilding after severe depletion that reached its nadir during the 1990s (Figure 6.2 and Figure 6.3). Even so, high seas bottom-fishery landings from the northwest Atlantic are second only to those of the southwest Atlantic. Summed over their long history or considered as potentially sustainable yields for the future, the northwest Atlantic high seas bottom fisheries overwhelmingly dominate those of the World Ocean as a whole.

The region's resources and ecosystem have been studied as comprehensively as any other worldwide. The same is true of the technologies deployed within it and the development of its fisheries, as well as the markets for its products and the social anthropology of its fishing communities. As a consequence there is extensive literature on the subject, including not only primary research papers and "grey" reports but also multiple book-length treatments. This wealth of information provides a depth of understanding when considering the complexities of the fisheries, and indeed the multiple drivers which have shaped them, which is simply unavailable for the high sea fisheries of other regions.

Separating high seas catches is problematic as many of the stocks on the Grand Bank straddle the jurisdictional boundary, and some are widely distributed. There has also been little interest in separating catches in this way in the past, as efforts have focused on assessing and managing catches at the stock level. It has also been difficult to separate high seas/EEZ catches by state, given that foreign vessels acquired licenses to fish in national waters during the 1980s. A close examination of catches for the entire region, which reflects – for the finfish at least – what has happened in the high seas, shows the enormous dominance of Atlantic cod in catches until the early 1990s, with reduced but seemingly sustainable catches of Greenland halibut and redfish, along with dwindling catches of flatfish and other species (Figure 6.3). Good catches of snow crab and northern shrimp supported the fishery during these lean periods, though shrimp stocks have now collapsed due to a combination of unfavourable environmental conditions and increased predation by recovering cod stocks. Estimates of current catches in the high seas for 2016 show the importance of redfish, Atlantic cod, and Greenland halibut, which collectively amount to a little over 40 000 tonnes. Other species make this up to 56 820 tonnes which is representative of catches in recent years (Table 6.1).

An indication of the general health of the straddling stock and high seas fisheries is provided by looking at the biomass and fishing mortality relative to target reference points (Table 6.2). In very approximate terms, the current biomass and fishing mortality are expressed in relation to the values that provide the maximum sustainable yield (i.e. B_{msy} and F_{msy}). In the table, red implies that the biomass is lower and/or the fishing mortality higher, when compared to the reference points; green implies the opposite, which indicates that the stock and /or fishing mortality are at desirable levels for a sustainable

FIGURE 6.1
Map of the northwest Atlantic Ocean. showing NAFO convention area (shaded)

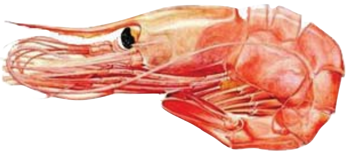


200 nautical mile arcs, 2 000 m isobath (GEBCO), FAO fishing areas.

Source: FAO VME Database, Mercator projection.

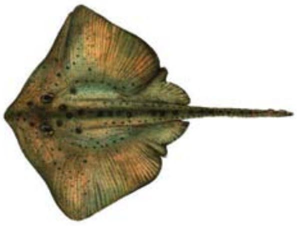
FIGURE 6.2
Principal demersal resource species of the high seas of the northwest Atlantic

northern shrimp
Pandalus borealis[1]

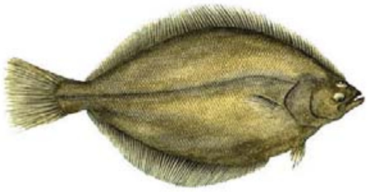


snow crab
Chionoecetes opilio[2]

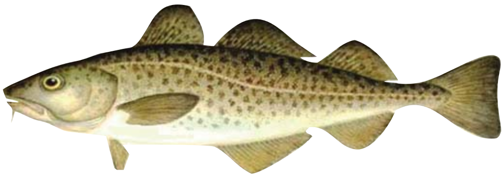
thorny skate
Amblyraja radiata[1]



American plaice
Hippoglossoides platessoides[1]

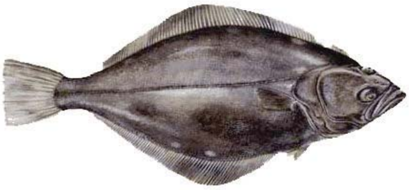


Atlantic cod
Gadus morhua[1]

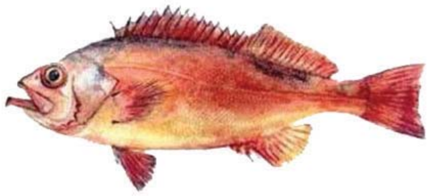


Atlantic halibut
Hippoglossus hippoglossus[1]

Greenland halibut
Reinhardtius hippoglossoides[1]



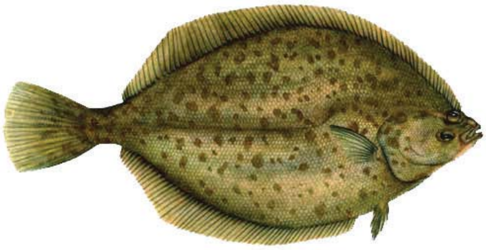
redfish
Sebastes spp[1]



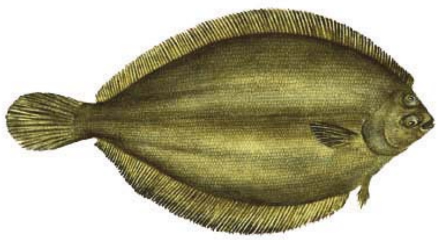
roughhead grenadier
Macrourus berglax[1]

white hake
Urophycis tenuis[1]

yellowtail flounder
Limanda ferruginea[1]



witch flounder
Glyptocephalus cynoglossus[1]



Source:
[1] www.nafo.int/Science/Species
[2] DFO, 2018.

TABLE 6.1
High seas bottom fisheries catches in in the northwest Atlantic Ocean in 2016

Principal gear	Principal grounds	Principal flag states	Target species	2016 catch *(tonnes)*
Bottom (and deep midwater) trawl	3LMNO upper continental slopes	Portugal, Russia, Spain, Estonia	redfish	21 671
Bottom trawl & longline	Flemish Cap (3M)	Portugal, Spain, Faroe Islands	Atlantic cod	13 903
Bottom trawl	Flemish Pass	Spain, Portugal, Russian Federation, Estonia, Japan (Canada catch removed)	Greenland halibut	8 615
Bottom trawl	Southeast Shoal	Canada, USA, Japan	yellowtail flounder	4 362
Bottom trawl	Grand Bank and Flemish Cap (3LNO)	Portugal, Spain	thorny skate	3 521
Bottom trawl	Grand Bank, Flemish cap	Spain, Portugal, Russian Federation, USA, Japan	American plaice	1 164
Pots	Grand Bank (3N only)	Canada	snow crab	742
Bottom trawl	3LNO	Faroe Islands, Portugal, Russian Federation, Spain (bycatch only)	Atlantic cod	656
Longline	3NO continental slope	Canada, Portugal	Atlantic halibut	543
Bottom trawl	Grand Bank, Flemish cap	Portugal, Spain (bycatch)	witch flounder	412
Bottom trawl	Flemish Pass	Portugal, Spain (mainly bycatch)	grenadiers	380
Bottom trawl	Grand bank	Portugal, Spain	white hake	379
Bottom trawl	Grand bank	Portugal, Spain (bycatch)	haddock	239
Bottom trawl and longlines	3LMNO	Spain	deepwater sharks (mostly Greenland shark)	233
Bottom trawl	3L continental slope and Flemish Cap	Closed fisheries	northern shrimp	0
TOTAL				56 820

Source: Table 2 (daily catch "CAT" reports) in NAFO, 2017; Snow crab estimated from Division 3N catch using STATLANT 21A tool on NAFO website https://www.nafo.int/Data/STATLANT).

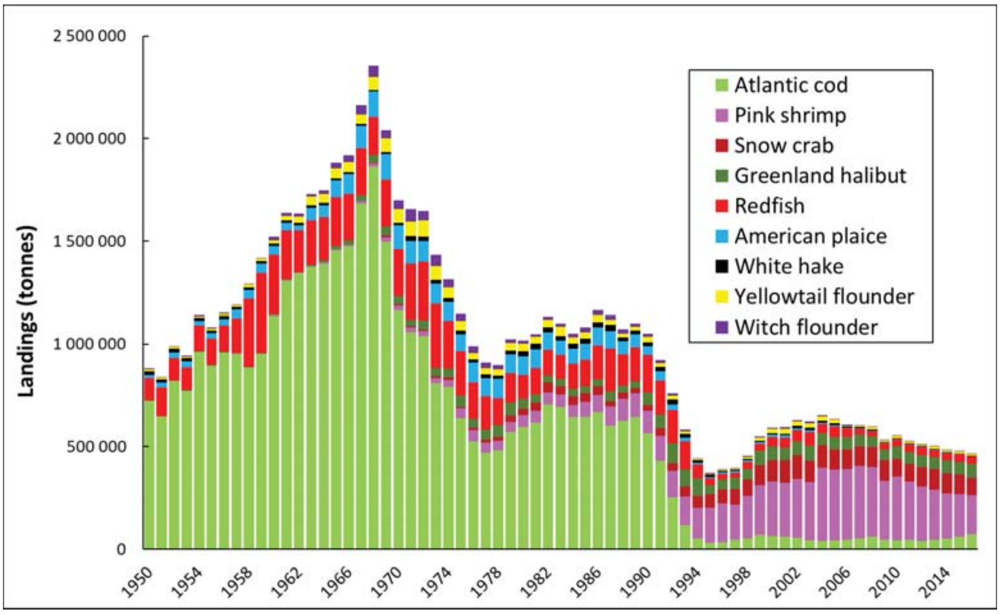
fishery. The biomass and fishing mortality in the orange cells are intermediate. This 'traffic-light' system provides a convenient but simplistic overview, and many factors need to be considered when assessing the true state of the stocks and fishery.

The dates of fisheries closed to directed fishing are shown where its biomass reached a critically low level (but in all cases bycatch has been allowed subject to defined limits and move-on rules) (Table 6.2). The closures, depending on the stocks, have resulted from either excessive fishing pressure in the 1990s and/or unfavourable environmental conditions hindering successful recruitment. Assessments are not undertaken every year, hence the blank cells in the table. The only fisheries that have never been closed are alfonsino (sporadic and with no accepted assessment), Greenland halibut, the 3M and 3O redfish stocks,[1] thorny skate and white hake, though even these have been below desirable levels at times. Stocks of American place, 3NO Cod, witch flounder and more recently northern shrimp, continue to be closed with no clear signs of recovery despite low fishing mortality. Other stocks have been closed for limited periods and have recovered sufficiently to reopen the fishery.

Various flag states were involved in the different fisheries, amongst which Canada, Faroe Islands, Portugal, the Russian Federation and Spain were particularly prominent – Canada alone being involved in the snow crab fishery. NAFO received reports of almost 57 000 tonnes of catch (directed and bycatch combined; NAFO, 2017). That

[1] For brevity, stocks will be referenced by the area where they are caught.

FIGURE 6.3
Landings of principal "offshore" species in the northwest Atlantic region (EEZs and high seas combined)



Source: FAO, 2019a.

overall total catch in 2016 was greater than the high seas bottom-fishery catch taken in any other region, except the southwest Atlantic. The 3LMNO redfish fishery and 3M cod fishery both had catches of over 10 000 tonnes in 2016, followed by fisheries for Greenland halibut, yellowtail flounder, thorny skate and American plaice, which were all over 1 000 tonnes that year. There were several other principal international fisheries within the northwest Atlantic high seas that yielded small catches. The main fishing nations in the region's high seas are Portugal, Spain and the Russian Federation, taking some 70 percent of the groundfish catches (Table 6.1).

GEOGRAPHIC DESCRIPTION

The northwest Atlantic is here defined by the limits of FAO Major Fishing Area 21 – and has a sea area of 6 301 000 km² (Figure 6.1, Table 6.3). The high seas portion of the northwest Atlantic comprises a single contiguous area, delimited in part by the EEZs of Bermuda, the United States of America, Canada and Greenland.

The region is notable for the wide continental shelf that forms the Grand Bank, with the eastern and southern tips (known respectively and the "nose" and "tail" of the Bank) extending into the high seas, along with a considerable length of surrounding continental slope. The Grand Bank's southeast shoal spans the boundary of Canada's EEZ, such that the shallowest depth in the high seas is only a few tens of metres. The Flemish Cap lies in the high seas to the east, with steep flanks and a broad flat top shoaling to a minimum depth of around 125 m. The combined high seas area above the 200 m isobath is 30 000 km², which is three times larger than the equivalent area of the Patagonian Shelf in the high seas of the southwest Atlantic.

The Flemish Pass lies between Grand Bank and Flemish Cap, and includes extensive areas of potentially trawlable, fishable ground of relatively smooth bottom at 200–2 000 m. As a consequence, the median length of commercial trawl sets in the high seas is 28 km, while some individual sets exceed 65 km (Cogswell *et al*., 2010). The seabed is more typical outside the Pass, with flat sandy or gravelly areas on the tops of Grand Bank and Flemish Cap and steep and rugged terrain along their flanks. Overall, to the east of Newfoundland, there is some 120 000 km² of high seas seabed shallower than 2 000 m.

TABLE 6.2
Summary of state of the stocks between 2007 and 2018, as assessed by the NAFO Scientific Council

Stock (and dates of closed fisheries)	2007[1]	2011[1]	2012	2013	2014	2015	2016	2017	2018
Alfonsino in Division 6G									-
(Bottom fishing closure since 2008, VME measure)									-
American plaice in Division 3LNO	B	B	B		B		B		B
(closed since 1995, rebuilding plan, harvest control rule)	F	F	F		F		F		F
American plaice in Division 3M	B	B			B			B	
(closed since 1996)	F	F			F			F	
Cod in Division 3NO	B			B		B			B
(closed since 1995, rebuilding plan, harvest control rule)									
Cod in Division 3M	B	B	B		B	B		B	B
(closed 1988–1990, 1999–2010)		F	F	F	F	F		F	F
Greenland halibut in SA 2 and Division 3KLMNO	-	-	-	-	-	-	-	-	-
(never closed, harvest control rule)	-	-	-	-	-	-	-	-	-
Northern Shrimp in Division 3LNO				B	B	B	B	B	
(closed since 2015)	F			F	F	F	F	F	
Northern Shrimp in Division 3M	B	B		B	B	B		B	
(closed since 2011)	F	F		F	F	F		F	
Redfish in Division 3LN	B		B		B				
(closed 1998–2009)	F		F		F				
Redfish in Division 3O	-			-			-		
(never closed)	F			F			F		
Redfish in Division 3M	B	B							
(never closures)	F	F		F		F		F	
Thorny skate in Division 3LNOPs	B		B		B		B		B
(never closed)	F		F		F		F		F
White hake in Division 3NOPs	-	-		-		-			
(never closed)	-	F		F		-			
Witch flounder in Division 3NO	-	-			B	B	B	B	B
(closed 1995–2014)	F	F			F	F		F	F
Witch flounder in Division 2J+3KL	B			B			B		
(closed since 1995)	F			F			F		
Yellowtail flounder in Division 3LNO	B	B		B		B			B
(closed 1995–1996)	F	F		F		F			F

[1] The colour coding for 2007 and 2011 was provided by the author, based on values provided in the NAFO Scientific Council (SC) reports, whereas those for 2012–2018 were provided by the NAFO SC.
- indicates status unknown relative to the reference points.
Blank cells indicate no assessments undertaken.
The stock biomass (**B**) and fishing mortality (**F**) are colour-coded to indicate these are at: undesirable levels (red), intermediate levels (orange) or acceptable (green), relative to limit reference points. Fishery closures are given in parentheses.
Source: NAFO Scientific Council reports 2007–2018, NAFO website.

TABLE 6.3
Area statistics for the northwest Atlantic Ocean

Geographical area	Surface area (km²)
Total sea area	6 301 000
Area of high seas	2 637 000
Area of High seas shallower than 200 m	30 000
Area of high seas shallower than 400 m	60 000
Area of high seas shallower than 1 000 m	91 000
Area of high seas shallower than 2 000 m	140 000

The rest of the high seas portion of the northwest Atlantic is mostly too deep for fishing. Orphan Knoll is an isolated, flat-topped feature lying north of Flemish Cap peaking at around 1 800 m and with no evidence of commercial fishing activity (Thompson and Campanis, 2007; Campbell, 2016). The Corner Rise seamounts and New England seamounts are at the southern boundary of the region, and are generally too deep for bottom trawling. Bottom trawls are no longer permitted on these seamounts owing to closures to protect vulnerable marine ecosystems (VMEs), but midwater trawls are used occasionally on the flat-topped Kükenthal Peak on Corner Rise Seamount, peaking at 828 m; catches for 2013–2017 were around 90 tonnes per year (Thompson and Campanis, 2007; Campbell, 2016, NAFO Secretariat, personal communication).

ECOSYSTEMS AND RESOURCE SPECIES

Oceanography and variability

The Gulf Stream forms the northwest Atlantic's western boundary current, though it breaks away eastward from the continental margin near Cape Hatteras, and thereafter has no direct interaction with the bottom fishing grounds. The Corner Rise area lies east and south of the Stream, in the oligotrophic core of the North Atlantic's subtropical gyre. At continental-shelf depths, the fishing grounds of the Grand Bank and Flemish Cap are flooded by the very cold (≈ 0 °C) low-salinity water of the Labrador Current, which flows south from the Arctic. The major branch of this current follows the shelf break, passing clockwise around Grand Bank, while other portions contribute to the waters on the Bank itself. There, they form a Cold Intermediate Layer with warmer fresher water (freshened by ice melt) at the surface in summer. At depths greater than about 200 m, water movements are more complex but a portion of the cold (< 3 °C) Labrador seawater flows through the Flemish Pass and floods the region's deeper high seas fishing grounds. Slightly warmer (≈ 4 °C) waters from the south sometimes impinge on the seabed around the tail of the Bank and around the southeastern flank of Flemish Cap, at depths of 200–2 000 m.

Most of the resource species fished in the region's high seas approach the northern limits of their distributions and the cold limits of their temperature tolerances. Small variations in oceanographic conditions can therefore have large synchronized effects on the populations, particularly affecting recruitment but also growth and mortality rates (Koslow, 1984; Rothschild, 2007; Frank *et al*., 2016). The North Atlantic Oscillation (NAO)is a pattern of anomalies in the atmospheric pressure differential between Iceland and the Azores. Positive NAO values are associated with a stronger flow of the Labrador Current and an increased southward transportation of winter ice which, by introducing additional, very cold water to Grand Bank, lowers the temperature at continental-shelf depths there (see Drinkwater, 2002; Stige *et al*., 2006). Positive values are also associated with stronger winds across the Labrador Sea in winter, which promote an enhanced formation of deep, cold Labrador sea water (Yashayaev *et al*., 2008); this in turn produces a greater movement of that water across the deeper fishing grounds on the continental slopes and in Flemish Pass, thereby lowering the temperatures in these areas as well.

The NAO time series has been reconstructed for the past millennium. While inter-annual variability was high, its values were more often positive than negative (implying cold conditions on the Grand Banks) from the mid-nineteenth century until about 1930. It then came to average strongly negative (Ortega *et al*., 2015), remaining in that state into the early 1970s. Thereafter, it was often positive and particularly so during the years around 1990 (Stige *et al*., 2006). Systematic oceanographic monitoring of a station off St. John's, Newfoundland, where the inter-annual and longer-term variability are representative of those on the Grand Banks (Drinkwater, 2002), began in the late 1940s. As expected for a period with generally negative NAO, recorded bottom temperatures were initially relatively warm. They became warmer still during the 1960s, then plunged to sharply colder conditions in the early 1970s. This was followed by a warming into the early 1980s, another sharp cooling in the middle of that decade, before a partial recovery that did not reach the long-term average temperature. The early 1990s brought another steep fall to record lows before recovery to above-average temperatures began in the middle of the decade (Drinkwater, 2002; Rice, 2002). From 1996 until 2013, the index was almost consistently above average and, in 2011, reached its highest level since monitoring began. It has since dropped below average again (Colbourne *et al*., 2016). The implications for fishery resources of those trends in physical factors are taken up after introducing the species concerned.

Ecology and resource species

The ecosystems on and around the Grand Bank, including those on the high seas fishing grounds, generally follow expectations for cold–temperate continental shelves. To simplify, there are brief phytoplankton blooms in spring and autumn, which are cropped by planktonic herbivores, principally calanoid copepods, which are eaten in their turn by predators at higher trophic levels. Capelin is particularly important among the latter, as are euphausiid krill along the shelf break and upper continental slope, though they also feed as herbivores. As in other marine ecosystems, non-living organic matter, processed through a microbial food web, plays a major role, as does a rich gelatinous plankton community. Benthic ecosystems are also important to the demersal fish resources, as is benthic/pelagic coupling.

Most higher taxa are not as diverse on Grand Bank as they are in either the northeast Atlantic or the North Pacific, but a wide variety of demersal species nonetheless has been, and continues to be, exploited (Figure 6.2). Historically, Atlantic cod was the dominant top fish predator but the ease with which it could be salted and dried for transport to market led to it being among the region's principal resource species which suffered early depletion, beginning in the sixteenth century and increasing thereafter.

MANAGEMENT OF HIGH SEAS BOTTOM FISHERIES

International Commission for the Northwest Atlantic Fisheries (ICNAF)

Multilateral management of the region's fisheries began with the International Commission for the Northwest Atlantic Fisheries (ICNAF), which was founded in 1949 as one of the World's first RFMOs.[2] Their mandate was for fisheries research and management within the northwest Atlantic, including both the present-day EEZ and high seas areas. The national fisheries agencies of the North Atlantic nations, working through ICNAF as much as the International Council for the Exploration of the Sea (ICES), went on to establish many of the foundations of marine fisheries science and management. The ICNAF Commission, without the support of a unifying international agreement, proved unable to prevent over-exploitation of the principal groundfish resources of the region, from exploitation from multiple fishing

[2] https://www.nafo.int/About-us/ICNAF

nations. This was a major contributing factor to coastal states' decision to extend their jurisdictions to include EEZs at the end of the 1970s.

Northwest Atlantic Fisheries Organization (NAFO)

The Convention on Future Multilateral Cooperation in the Northwest Atlantic Fisheries came into force in 1 January 1979, forming the Northwest Atlantic Fisheries Organization (NAFO). Recently, this was modernized to account for, among other things, a greater awareness of the need to follow an ecosystem approach to fisheries and to protect dependent and associated species that interact with fishing operations. The amended convention, the Convention on Cooperation in the Northwest Atlantic Fisheries, entered into force on 18 May 2017. NAFO currently has 12 contracting parties: Canada, the United States of America, France (St. Pierre et Miquelon), Denmark (in respect of the Faroe Islands and Greenland), Cuba, Iceland, Japan, the Republic of Korea, Norway, the Russian Federation, Ukraine, and the European Union; the first four being costal states.

In keeping with the ideas of the 1970s, the declared objective of NAFO concerned the rational exploitation of fishery resources. In 2007, the contracting parties agreed to amend the Convention to broaden the focus on:

> *ensur[ing] the long-term conservation and sustainable use of the fishery resources in the Convention Area and, in so doing, to safeguard the marine ecosystems in which these resources are found.*

The NAFO Convention Area includes the entire northwest Atlantic extending to the coastlines of the North American continent and Greenland. A distinct NAFO Regulatory Area (NRA) is recognized, comprising the high seas portion of the convention area. This has been divided into subareas, divisions and sometimes subdivisions (Figure 6.4).

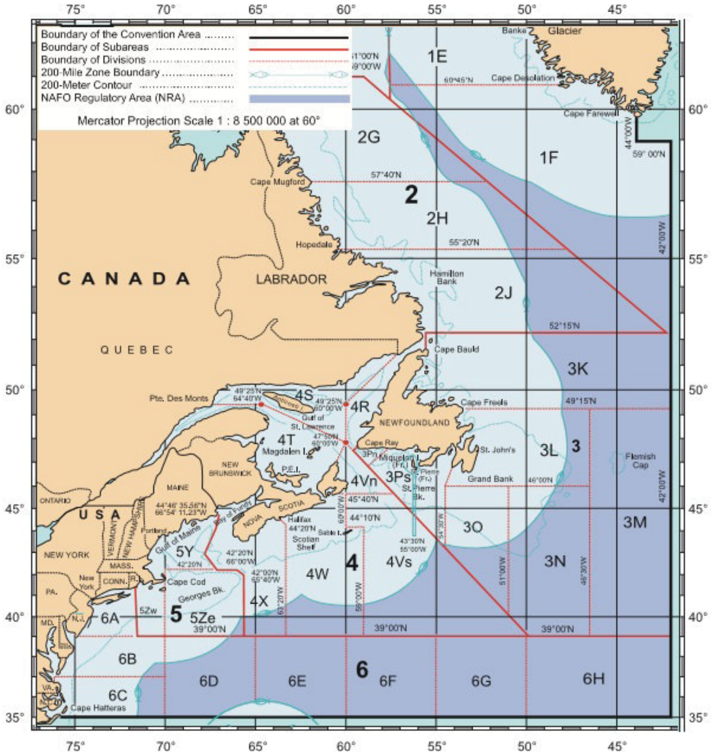
The convention applies to all fishery resources in the convention area, with specified exceptions for taxa that fall under the mandates of other international bodies (salmon, tunas, marlins and cetaceans) and for the sedentary species that, under UNCLOS, are subject to national jurisdiction out to the limits of the continental shelves. In practice, NAFO has largely limited its concern to the finfish and shrimp fisheries in its NRA and those for straddling resources. The division of responsibilities between NAFO and Canada has changed over time, with Canada exerting de facto jurisdiction over all benthic shellfish in the fishable area east of Newfoundland, except northern shrimp.

The activities of NAFO are coordinated by its Commission (administration and fisheries management, which are divided into separate bodies called the General Council and Fisheries Commission prior to March 2017) and its Scientific Council (scientific advice and research coordination), all comprised of representatives from contracting parties and including various observers, together with the Secretariat.

The management of NAFO fisheries is controlled through the NAFO Conservation and Enforcement Measures (CEMs).[3] These include measures that manage the fisheries directly (e.g. catch quotas) and the procedures needed to implement such limits, in addition to conservation objectives, rebuilding strategies, harvest control rules and other restrictions on the organization's own future decision-making (Table 6.4). The CEMs provide for management of 19 discrete stocks of 11 species or species groups, although 9 of the 19 are currently closed to directed fishing. The primary conservation limit in each case is a total allowable catch (TAC) divided into national quotas and invariably includes regulations to minimize bycatch. The 3M northern shrimp fishery is additionally subject to effort limits, which are currently set to zero, meaning that the fishery is closed to directed fishing. The catch limits are also subject to minimum fish sizes, minimum mesh sizes and a variety of controls on trawl gear. There are

[3] https://www.nafo.int/Fisheries/Conservation

FIGURE 6.4
The northwest Atlantic showing the NAFO regulatory area, part of the convention area, and the statistical divisions



Source: Cropped from NAFO, 2018c.

also various area-based measures which maybe year-round or seasonal. The CEMs also include a full suite of administrative, inspection, surveillance, enforcement and reporting tools.

Finally, the CEMs also restrict bottom fishing and provide for protection of VME, primarily through spatial measures but in combination with an assessment, an exploratory fishery protocol and an encounter protocol (Campbell, 2016). The spatial measures include a bottom fishery "footprint" covering the area where bottom fishing is currently permitted, an area outside of this where there is currently no bottom fishing, and 14 closed areas to protect VMEs (Figure 6.5). Proposed new bottom fishing activity outside the "footprint" – or inside it if there is a significant change to the conduct or technology – is subject to the exploratory fisheries protocol.

Scientific support to management

The NAFO Scientific Council draws on the detailed fisheries statistics and 150 years of scientific research into the North Atlantic fisheries, their resource species and the region's ecology and oceanography (Table 6.5). There are long-established, high-quality time series of abundance and biomass estimates from science-directed, fishery-independent surveys, while the contracting parties have maintained and developed expertise in fisheries science. The advisory work of the scientific council is linked to the commission through annual requests for scientific advice necessary to support management decisions: these are wide-ranging and include advice on stock status and the setting of TACs, the protection of the marine ecosystem and bycatch reduction.

TABLE 6.4
NAFO Conservation and enforcement measures applicable to bottom fisheries that were in force during 2018

Measure	CEM[1]
Resource management	
TACs and national catch quotas for 19 stocks of 11 species (TACs for 9 stocks set to zero)	5.1–5.3, Annex I.A
Individual vessel quotas for Greenland halibut	10.4a
Limits on, and minimization of, bycatches of quota-controlled species	6
Landing of Greenland halibut	10.4b–10.6
Effort limit for shrimp fishery in Division 3M	5.1–5.3, 9.1–9.5, Annex I.B
Minimum fish sizes	14, Annex I.D
Mesh sizes and other gear requirements	13.1– 13.7, Annex III.A,B
200 m minimum depth for shrimp trawling in Division 3L	9.6
Squid close season, January to June	11
Conservation plans for cod, American plaice, shrimp, Greenland halibut and redfish	7–10bis
Ecosystem protection	
VME protections	15–17, 19–21, 22–24
Exploratory fisheries	18, 21, Annex I.E
Moratorium on 3NO capelin as food source	7.10
Sharks	12
Lost fishing gear	13.10–13.13
Fisheries administration	
Mechanism for closing fisheries	5.5–5.6, 5.15
Mechanisms for quota adjustments and transfers	5.9–5.12
Marking of vessels and gear, vessel list	13.9, 25, 26
Inspection and surveillance	31–41
Port state control	42–47
Observers	30
Vessel monitoring systems	29
IUU vessels, non-contracting parties	49–56
Data reporting	27–28, Annex II.A, C– M
Data confidentiality	Annex II.B
Other	
Research fishing exempt from other CEMs but subject research plans	4

[1] The numbers given correspond to the Article designations in NAFO (2018c).
Measures grouped to correspond with the account given in the text.
Source: for full details see NAFO, 2018c.

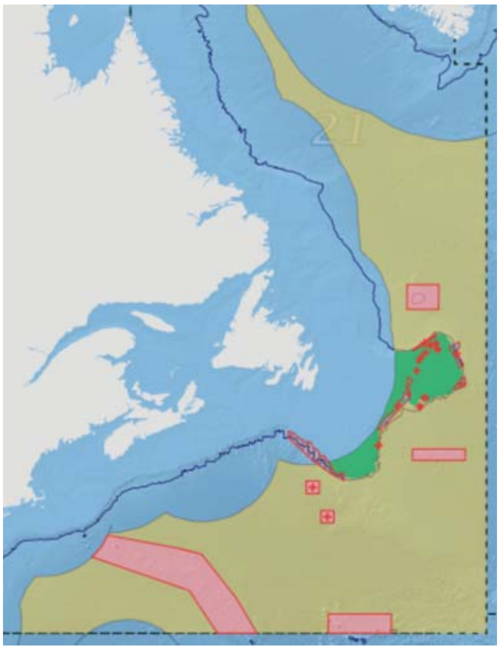
DESCRIPTION OF HIGH SEAS BOTTOM FISHERIES

Overview

Bottom fishing in what are now the world's high seas began some 450 years ago, with the French *pêche verte* on Grand Bank, taking Atlantic cod by handlines on the Southeast Shoal and elsewhere around the tail of the Bank. This catch was preserved in salt, landed in France and marketed "green". Two centuries later, a schooner fishery emerged that was broadly similar to the *pêche verte* (which it eventually replaced) but landed its salted catches on the coasts of the northwest Atlantic for subsequent drying. The technology of that fishery was transformed in the mid-nineteenth century, as it adopted longlining in dories in place of handlining from the deck of the schooner; it then continued under the Canadian flag until 1962, while the Portuguese continued handlining from dories until 1974.

Until the arrival of otter trawlers, cod fishing on the Grand Banks was conducted above 200 m depth. However, deep fishing in the modern high seas also began in the northwest Atlantic, when the New England Atlantic halibut longline fishery moved

FIGURE 6.5
Spatial measures relating to bottom fisheries and the protection of vulnerable marine ecosystems (VMEs) in 2018



Existing fishing area (footprint, green), closures to bottom fisheries to protect VMEs and other sensitive benthic habitats (red), and area where exploratory fishing protocols apply (orange and green).
Source: FAO, 2019b.

TABLE 6.5
Management units of resources fished in the high seas portion of the Grand Banks with bottom fishing gears

Species	NAFO subareas, divisions, or other defined area
Atlantic cod "northern" Flemish Cap Grand Bank	 2J+3KL 3M 3NO
haddock	3LNO
white hake	3NOPs
roundnose grenadier	Subareas 2+3
roughhead grenadier	Subareas 2+3
yellowtail flounder	3LNO
American plaice Grand Bank Flemish Cap	 3LNO 3M
witch flounder	2J+3KL 3NO
Greenland halibut	2+3KLMNO
Atlantic halibut	3NOPs+4VWX+5Zc
redfish	3LN 3M 3O
thorny skate	3LNOPs
northern shortfin squid	Subareas 3+4
snow crab	Crab Management Areas 3L200, 3N200 & 3O200
northern shrimp	3LNO 3M
Arctic surfclam	Banquereau & Grand Bank
Iceland scallop	3LN

onto the continental slope, including the flanks of Grand Bank, during the 1870s. This fishery has been continued ever since, mostly by Canadian fishermen, though it has sometimes contracted into what is now the Canadian EEZ, and at other times expanded to include the southern and eastern flanks of Flemish Cap.

Trawling was slow to develop in the northwest Atlantic,[4] but the first trawling in the modern high seas, globally, was again on the tail of Grand Bank: French trawlers targeted cod there from 1904 onwards, though their effort did expand greatly before the 1920s. They had great success when the cod were concentrated on the upper continental slope in the spring, and the trawlers were able to work down to 400 m depth. Their catches were salted for drying ashore, much as in the contemporary schooner fishery.

During the nineteenth century, the Massachusetts fishing industry increasingly turned to fresh fishing (often holding the catch on ice) to supply the Boston market and other urban centres, as railway connections developed. After the turn of the century, that sector began to turn to otter trawling and hence to catching a wider variety of species. The development of successful plate freezers in the 1930s led to consumer acceptance of fish in the form of frozen fillets. This technology was adopted in Newfoundland as part of a general effort to modernize the economy after 1945, with a new "wetfish" trawler fleet to supply the filleting plants. One outcome was trawling for haddock, flounders and redfish on Grand Bank. While in the early years the incentive to go as far to the eastward as the modern NRA for haddock or flounders was limited, from 1952 Canadian trawlers fished Division 3N for redfish. The upper-slope distribution of the fish in that division means that the fishing was probably in the high seas.

Soon thereafter, the great, global expansion of high seas bottom fisheries, which spread around the world by 1980, was initiated by the first two factory-freezer stern-trawlers from the former USSR[5] – which targeted redfish on Flemish Cap in 1956. Through the following decade and into the 1970s the former USSR fleet, and those of the other "Eastern Bloc" states of that era, exerted intense pressure on many resources in the northwest Atlantic, though they did relatively little fishing in what is now the NRA. Excessive fishing, by all of the states involved, interacted with reduced resource production resulting from colder conditions, leading to severe biomass declines by the mid-1970s. Stricter management, first by ICNAF and then by Canada, coupled with a warming trend, saw some recovery through to the mid-1980s. Renewed, and extreme, cooling and management failure, leading to overfishing, then led to a catastrophic collapse of most of the resources by the mid-1990s.

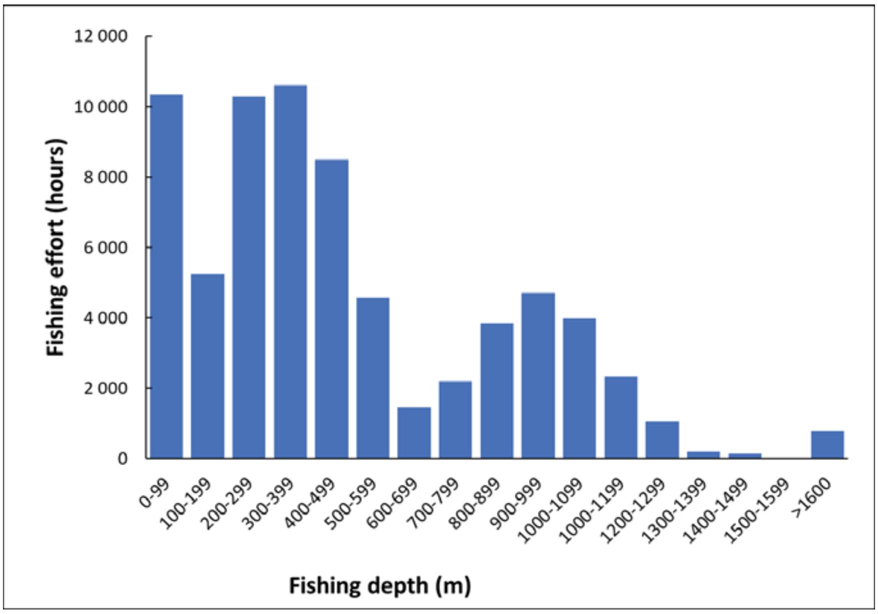
Meanwhile, in 1967, the former USSR began a fishery for roundnose grenadier which, by the 1990s, had expanded to depths as great as have been commercially fished anywhere, though primarily within what is now the Canadian EEZ. In the 1980s, and particularly the early 1990s, that fishery was overshadowed by a new exploitation of Greenland halibut, which worked down to equally great depths and into the high seas. Deep trawling has continued in the NRA ever since, and now forms a bimodal pattern with peaks around 300 m and 1 000 m (Figure 6.6). The current distribution of all bottom fishing within the NRA is seen as patchy, with the details provided in the individual fisheries included below (Figure 6.7).

Taken over the past 500 years, the 120 000 km^2 of seabed shallower than 2 000 m in the NRA east of Newfoundland has almost certainly yielded a greater demersal catch

[4] This statement concerns otter trawling. (Its precursor in Europe, beam trawling, was never much used in the northwest Atlantic.) The light-weight longlines originally developed for fishing from dories and subsequently widely used in the region are, confusingly, known as "line trawls" or simply "trawls" in fishing communities throughout New England and Atlantic Canada. Fishing with such gear is known as "trawling" but bears no relation to the mobile gear to which that term is applied internationally.

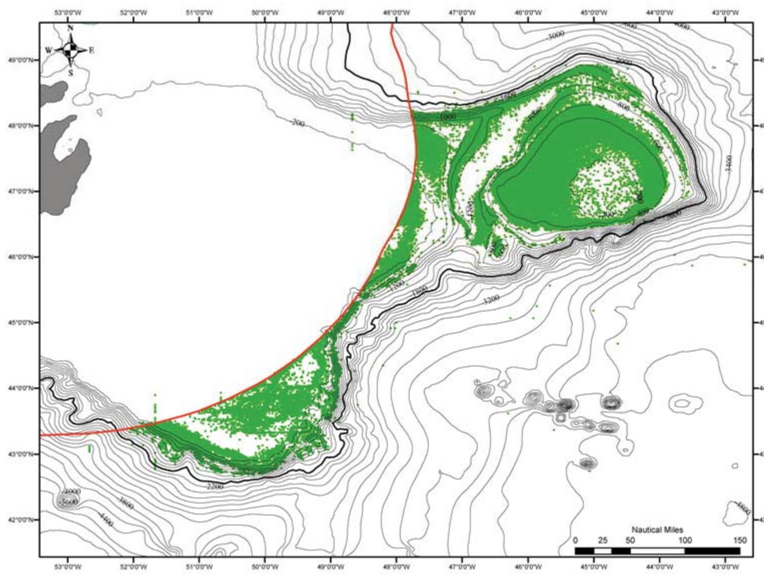
[5] Union of Soviet Socialist Republics (USSR) 1922–1991.

FIGURE 6.6
Depth distribution of groundfish fishing in the NAFO regulatory area excluding the Corner Rise area, during 2017



Source: re-drawn from NAFO, 2018b.

FIGURE 6.7
Distribution of fishing activity in the fishing footprint of the NAFO regulatory area as obtained from VMS position reports all vessels travelling at 0.5–5.0 knots (presumed fishing speeds) in 2017



Source: NAFO Secretariat, pers. com., 2018.

than the entirety of the world's modern high seas combined. Even following the severe resource depletions of the 1990s, the area continues to provide catches second only to those of the (even smaller) high seas portion of the Patagonian Shelf. In contrast to that high productivity, while the Corner Rise and New England seamounts were fished during the global development of seamount fisheries during the 1960s and 1970s, the total catch taken from them has only amounted to about 20 000 tonnes.

The following sections of this chapter examine those various fisheries in more detail, with particular reference to their (modern) high seas components. Regional perspectives, through to the loss of the principal resources, have been presented by Murawski *et al.* (1997) and Parsons and Beckett (1997).

Three, often contradictory, data sources are available for tracing the development of the northwest Atlantic high seas bottom fisheries (other than those for sedentary resources) since 1945. The primary source is comprised of the annual national reports of landings (not catches) made to ICNAF and NAFO. The reports contain considerable detail, which was formerly published in annual statistical bulletins and is now available via the NAFO "STATLANT 21A" and "21B" databases.[6] Thanks to the tabulations by Côté (1952), the catches of some of the fisheries can be extended back to long before ICNAF was founded in 1949, though others were not recorded in full detail until 1954. However, the only practical means of accessing the information is generally an online data-extraction tool provided by NAFO, which is limited to the "21A" database – hence to catches by NAFO Division and flag state, – and to the years since 1960. Where catch information is presented in the main text of this chapter, without another source cited, it has been drawn from that database.

While the STATLANT database contains the formally reported records of landings, the NAFO Scientific Council has sometimes had reason to doubt the accuracy of those records and has generated alternative time series, through careful study of assorted data sources. In such cases, the Council's conclusions are often tabulated in later stock-assessment reports that have used the approved catch values. Where they are relevant to this review and available, those values are quoted here, alongside the ones from the STATLANT database.

NAFO Division 3M lies entirely outside Canada's EEZ and hence all catches taken there come from high seas fisheries. Division 3LNO catches, by contrast, are largely within Canada's EEZ. Canadian fisheries there can spill over into the NRA, while other flag states have often had agreements allowing their vessels to harvest straddling stocks within waters under Canadian jurisdiction, even after that was extended in 1977. The STATLANT "21A" and "21B" databases cannot therefore provide information on specifically high seas fisheries directly.

In recent years, the annual NAFO Compliance Review has included tabulations of the numbers of vessels that operated in the NRA and the number of vessel-days spent in that those waters (available from 2004),[7] plus their catches taken in the NRA (available from 2012). Those values are based on real-time electronic reporting by the vessels concerned. They tend to be similar, but not identical, to the data extracted from "STATLANT 21".

Bottom trawl fisheries for Atlantic cod

Northwest Atlantic from 1904 to 1953

French trawlers began exploring Grand Bank in 1904 targeting Atlantic cod, including trawling in the modern high seas where their countrymen had started high seas hook-and-line fishing three and a half centuries earlier. The cod were salted on board and dried ashore, as in the schooner fishery of that era. Trawl-caught fish could not match the quality of those taken on hooks but the trawlers had the great advantage of being free of the constraint of bait supply. By the 1930s, a fleet of 30–40 vessels steamed across from France each year, salting cod for drying in St. Pierre and extracting cod liver oil on board. The French developed a new form of trawler in the late 1930s which could economically work the Grand Bank grounds out of home ports in Metropolitan France, without landing in St. Pierre. They were very large (1 600 GRT) and, being diesel-powered, could carry enough fuel for a full season of fishing and enough catch to

[6] https://www.nafo.int/Data
[7] https://www.nafo.int/Library/Documents/FC

make the transatlantic voyage economically viable (de Loture, 1949; Gueroult, 1960). French catches were upwards of 150 000 tonnes in the late 1920s and 1930s (Côté, 1952). As late as 1959, the French trawler fleet reported landing nothing but cod, implying a continued focus on saltfish.

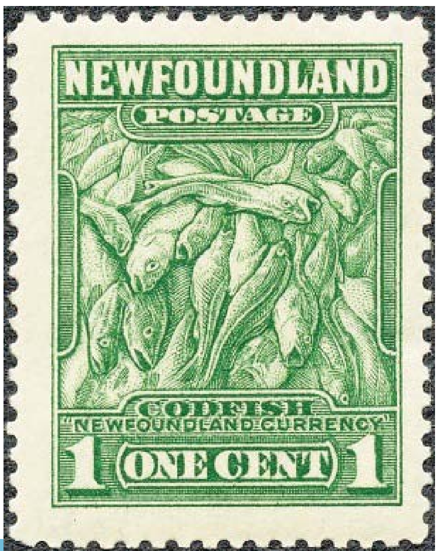
Spain sent its first trawlers, large vessels similar to those used by the French, to the northwest Atlantic in 1927 (López Losa and Amorim, 2012), landing cod but discarding haddock (McKenzie, 1946). The distant-water sector turned to the known Grand Bank grounds and the familiar salt-cod product, and 21 Spanish trawlers (averaging over 1 000 GRT each) went to the northwest Atlantic in 1949. From 1950, smaller Spanish pair trawlers fished the Grand Bank, raising the Spanish fleet there to 114 vessels in 1951, though their average size dropped to 400 GRT (Sinde Cantorna *et al*., 2007; López Losa and Amorim, 2012). The Spanish took 66 000 tonnes of cod from SA 2, 3 and 4 that year, using both pair trawls and single-vessel otter trawls – most being caught by pair trawling in SA 3 (Côté, 1952). The Spanish fleet modernized further after 1961, adopting factory-freezer stern-trawlers, with a massive increase in capacity. Where there had been 31 vessels of over 1 000 GRT in the Spanish fleet in 1961, there were 92 in 1975 (Sinde Cantorna *et al*., 2007; López Losa and Amorim, 2012).

The Portuguese fished the northwest Atlantic in the 1930s. The Portuguese continued fishing through the Second World War and landed 32 000 tonnes of cod from the northwest Atlantic in 1947, rising to 68 000 tonnes in 1950 (Côté, 1952; López Losa and Amorim, 2012). There were also Italian trawlers in the Grand Bank cod fishery in the 1930s (McKenzie, 1946), again using large trawlers of the French type. The Italians returned in 1948, taking a few thousand tonnes each year (Côté, 1952), but did not fish Grand Bank for cod after 1954. When trawlers began working out of Newfoundland in the late 1940s, their proper targets were haddock and flounders for filleting ashore, but they also took cod which were salted and dried (Andersen, 1998) in the manner of the French Grand Bank trawl fishery.

Northern cod

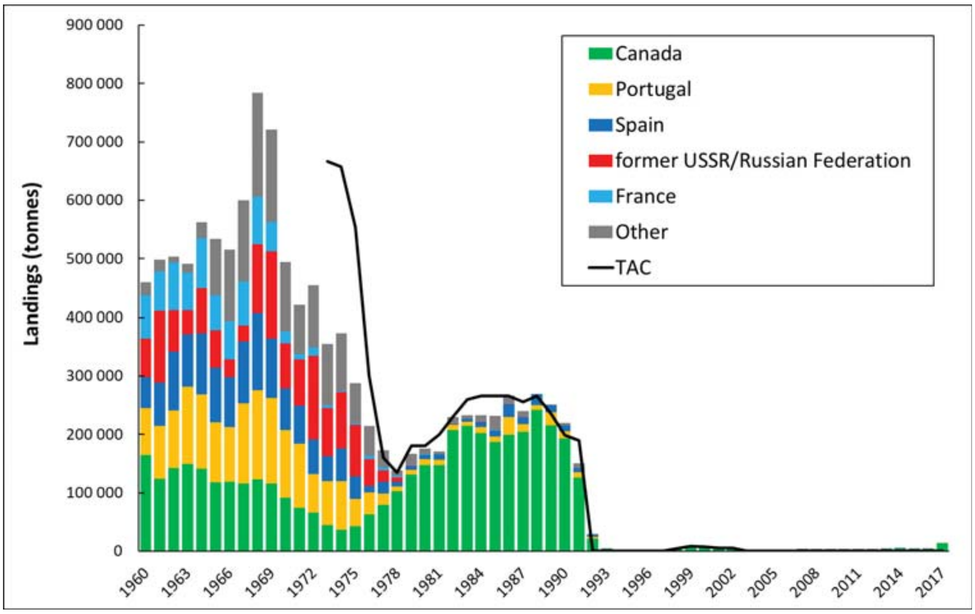
The "northern" cod stock (Division 2J3KL) straddles the Canadian EEZ/high seas boundary and is currently managed by Canada in cooperation with NAFO for the high seas component. Historically, these cod were taken by the Newfoundland inshore fishing industry and have been referred to as "Newfoundland currency" (Figure 6.8). Formerly, this was Canada's largest groundfish fishery with overall annual catches of around 800 000 tonnes in the late 1960s, falling to 225 000 tonnes in the 1980s and collapse in the early 1990s (Figure 6.9a). The fishery operated at 200–500 m depth. Canada set a TAC for Canadian vessels from 1973, soon after the peak catches were starting to decline, with most of the catches being taken by the distant-water fleets of France, Spain, Portugal, the former USSR and others. The establishment of the Canadian EEZ in 1977 resulted in a dramatic change in the proportion of the catch taken by Canada who dominated the fishery for the next 15 years and into the collapse period. Canada closed its directed cod fisheries on the Division 2J3KL stock in 1992 and NAFO followed for the high seas part of Division 3L in 1994; NAFO itself never set TACs on this stock.

FIGURE 6.8
Newfoundland stamp from 1932 depicting cod as "Newfoundland currency"

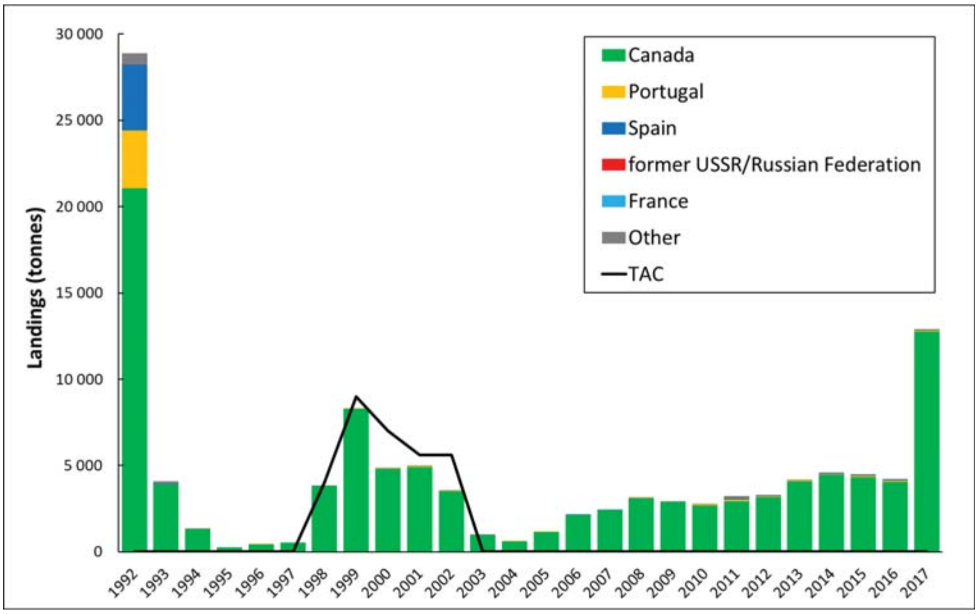


The 2J3KL cod resource continued to decline sharply for a few years after the directed fisheries

FIGURE 6.9
Landings of northern cod in Division 2J3KL (EEZ and high seas) by flag state, showing the Canadian set TAC for: (a) 1960–2017, and (b) detail for 1992–2017



(a)



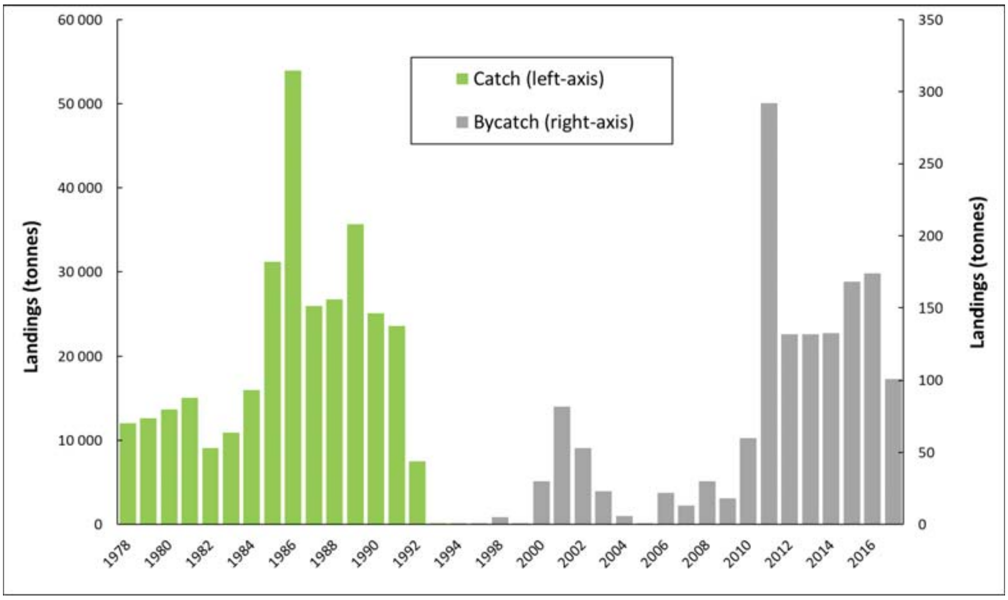
(b)

Source: STATLANT 21A and NAFO SC reports, NAFO website.

were closed but showed signs of recovery around 1997. Canada reopened the 2J3KL cod fishery from 1998–2002 with annual TACs of 4 000–7 000 tonnes, but this was short-lived and the fishery has not been opened since. However, a small fishery is permitted within Canadian waters under an individual license system to support inshore fishers and to monitor the stocks, with catches around the 5 000-tonne level; these reached a peak at nearly 13 000 tonnes in 2017, but this is likely to be much reduced in 2018 (Figure 6.9b). A small recovery in the stock was seen over this recent period, but prospects now look less promising (Brattey *et al*., 2018). Resource biomass remains far below the level needed to support an optimal sustainable yield and no directed, offshore fishery has been reopened. The 3L cod landings remain confined to inshore subsistence fishing on the Newfoundland coasts, plus very minor bycatches taken under various flags.

Historical catches in the high seas of this stock are not clearly known, but those from non-Canadian vessels fishing in Division 3L, which includes both EEZ and the "nose of the Grand Bank" high seas area, likely reflect high seas catches after 1977. These peaked at over 50 000 tonnes in 1986 before declining rapidly in the early 1990s to below 100 tonnes. After the closure of the high seas directed fishery in 1994, the catches reflect bycatches while targeting other species, which were low until after 2010 when they were 101–292 tonnes annually. The 2016 catch was 174 tonnes, mainly by Portugal and the Russian Federation (Figure 6.10).

FIGURE 6.10
Likely high seas catches of northern cod in Division 3L as targeted species and as bycatch



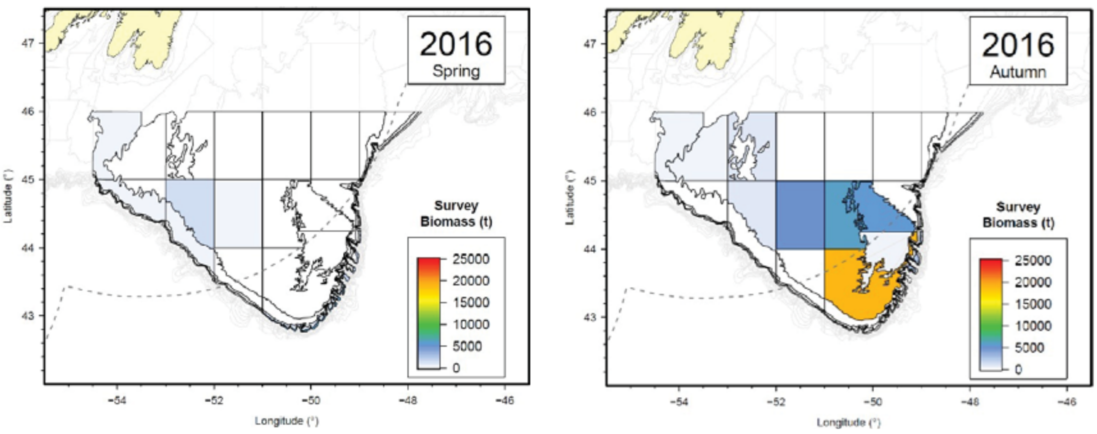
Catches by Canada and France (St. Pierre et Miquelon) were removed as representing probable catches in the EEZs.
Source: STATLANT 21A and NAFO SC reports, NAFO website.

Southern Grand Bank cod

Cod in Division 3NO inhabit the southern Grand Bank and have occurred mainly, at least in recent years, around the tail of the Grand Bank, with lower densities occurring elsewhere both in the Canadian EEZ and high seas (Figure 6.11). They are distributed over the shallower part of the bank in the summer, particularly the "Southeast Shoal" area, and on the slopes of the bank during the winter. The fishery has been closed to directed fishing since February 1994. The proportion of the catch occurring in the high seas prior to 1994 is unknown, but assuming that Canadian catches represented the EEZ catches then it is likely that some 50–70 percent of the catches are taken in the high seas (Rideout *et al*., 2018).

The Division 3NO management unit approximately covers the Grand Banks cod stock, which was the primary target of fisheries from the sixteenth century *pêche verte*, through the nineteenth-century schooner "dry fishery" fisheries to the twentieth-century salt-cod trawling pioneered by the French. By 1954, most of those fisheries were far into their terminal decline, leaving little more than the Portuguese "White Fleet" trawlers as well as dory vessels, and Spanish trawlers – both otter

FIGURE 6.11
Biomass distribution of southern Grand Bank cod in Division 3NO in: (a) spring 2016, and (b) autumn 2016



(a) **(b)**

Source: Rideout *et al*., 2018.

trawlers and pair trawlers. Landings have fluctuated widely according to variations in recruitment, showing peaks in 1954, 1968 and 1986. Catches in the 1966–1974 period were particularly high, mainly by vessels from the former USSR and Spain, and to a lesser extent by Canada in 1980–1992 when the stock was at a relatively low level (Figure 6.12a). TACs were introduced from 1973 but they did not become restrictive until five years later, and were exceeded from 1982 until 1991. The stock recovered somewhat in the 1980s before declining to very low levels. The directed fishery was closed in the Canadian zone in 1993 and in the NRA from 1994, and it has not been reopened (Rideout *et al*., 2018).

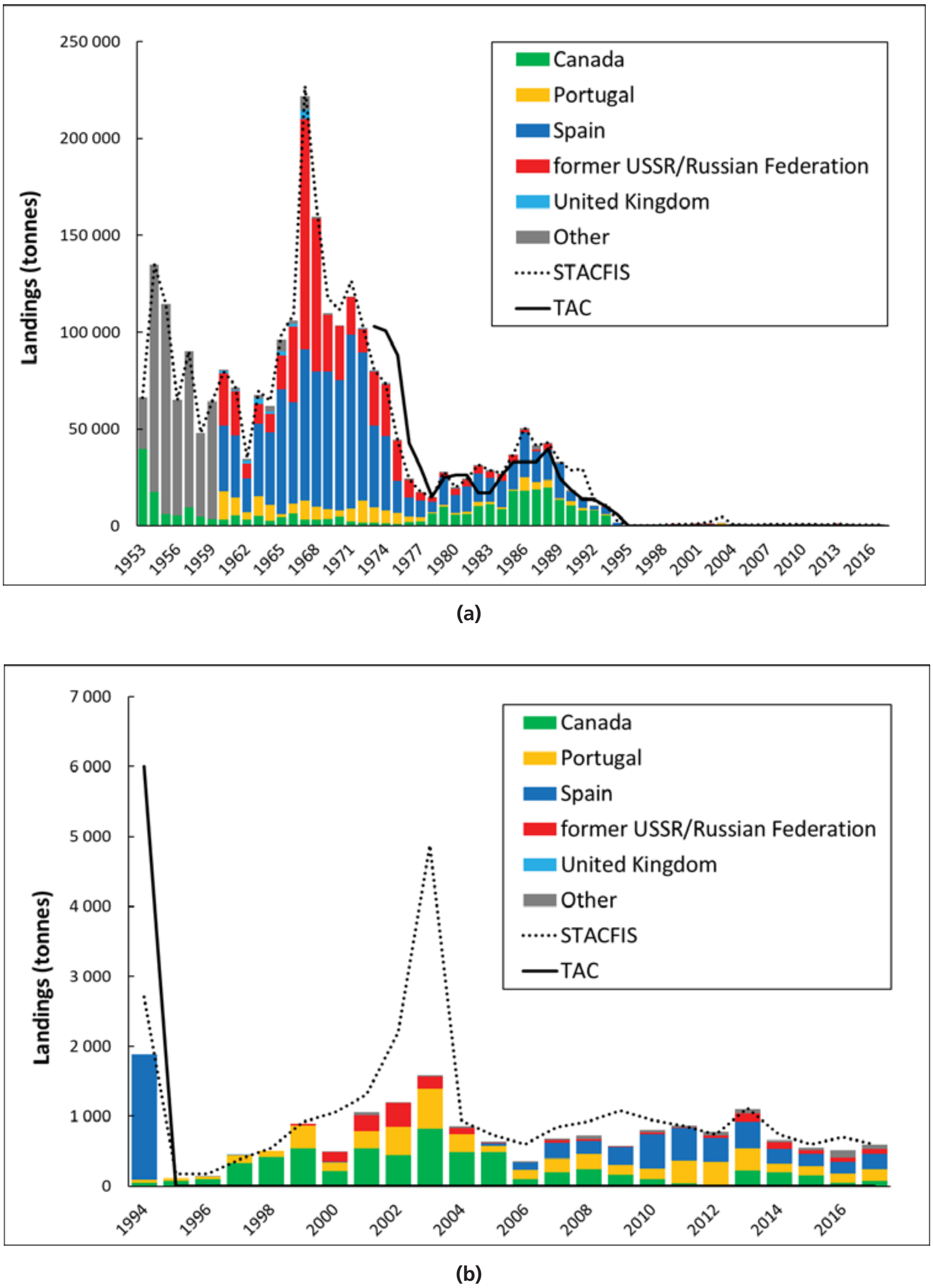
The 3NO cod landings have been limited to (nominal) bycatches since the mid-1990s. In more recent years, the cod bycatch comes from directed fisheries for yellowtail flounder, redfish and hake (Rideout *et al*., 2018). The NAFO Scientific Council has questioned the reported landings (as represented in the STATLANT 21A database) and has produced its own alternative estimates of catches for years from 1991 onwards. Those have generally been somewhat higher than the reported values but only markedly so for 1991 itself (when the Scientific Council figure of 29 000 tonnes doubled the sum of national reports), 2002–2003 and 2009. Since the moratorium, catches increased from 170 tonnes in 1995, peaked at about 4 800 tonnes in 2003 and have settled at 600–1100 tonnes since that time (Figure 6.12b). Division 3NO cod catches were 516 tonnes in 2016.

Research surveys showed that the spawner stock biomass (SSB) increased from 2010–2015 but then decreased slightly since, mainly as a result of poor recruitment. The SSB is estimated at 18 537 tonnes for 2018 against a target SSB of 60 000 tonnes. The fishing mortality on the stock remains at an acceptably low limit. Rebuilding is therefore dependent upon good recruitment, though the prospect of recovery is currently poor (Rideout *et al*., 2018, NAFO, 2018a). Division 3NO remains closed to directed cod fishing.

Flemish Cap cod

Flemish Cap was deemed too deep for handlining by the fishermen of the *pêche verte* (de la Morandière, 1962–1966). When longlining was introduced, it became necessary to anchor the vessels and the depth of the Cap discouraged that (de Loture, 1949). Thus, while some cod were doubtless taken from the ground, it appears not to have

FIGURE 6.12
Reported landings and estimated catches of Atlantic cod from Division 3NO for: (a) 1953–2017, and (b) detail for 1994–2017, showing landings by the principal flag states, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website; Rideout *et al*., 2018.

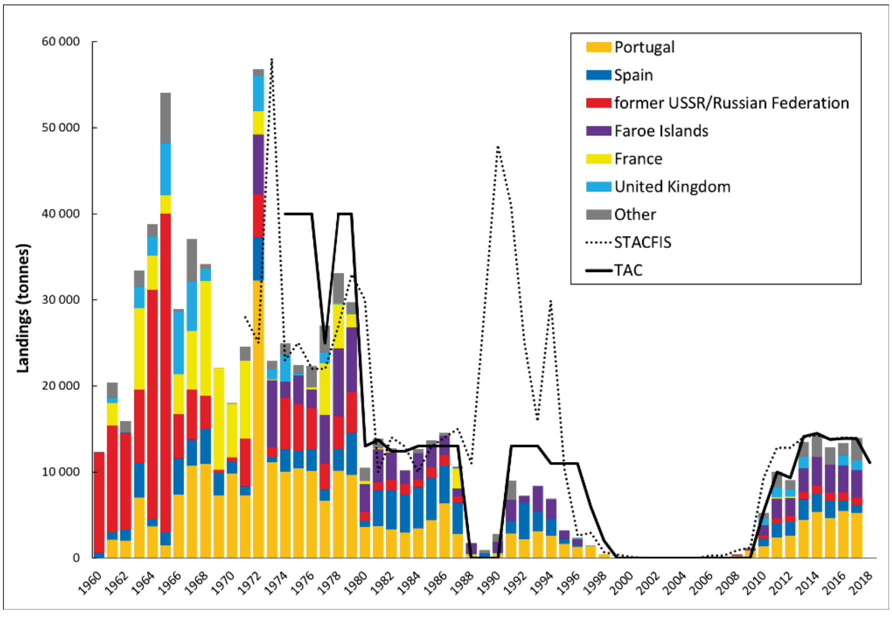
been regularly fished until the growth of otter- and pair trawling after 1945. Indeed, reported cod landings from Division 3M remained low until the advent of the full-scale former USSR redfish fishery in 1957 which took 16 000 tonnes of 3M cod (along with 32 000 tonnes of redfish) that first year. The former USSR's reported cod landings peaked at 37 000 tonnes in 1965 but dropped to 5 000 tonnes the following year as the fleet moved elsewhere. France, Spain and the United Kingdom of Great Britain and Northern Ireland also fished the Cap for cod during the 1960s, but only the Portuguese took substantial catches, with their landings peaking at 32 000 tonnes in 1972. By then, according to modern assessments, the resource was under sufficient pressure that it was recruitment-driven, the 1973 year-class being particularly strong, as the 1985 year-class was to be later (González-Troncoso, 2015).

From 1972, the Portuguese, Spanish and former USSR trawlers were joined by Faroese longliners, while French vessels returned to the Cap later that decade. Together, they kept overall 3M cod catches at around 30 000 tonnes each year. From 1980, the TAC which had rarely been restrictive was cut and annual reported landings were thereafter in the 10 000–15 000 tonnes range, with Spain, Portugal and the Faroe Islands as the major flag states.

Subsequent events are less certain. The formal reports of landings suggest that resource depletion and the consequent management restrictions saw the fishery decline again, from a catch of nearly 15 000 tonnes in 1986 to 1 700 tonnes two years later, when directed fishing was closed for three years. Biomass appears to have responded positively, though an increase in recruitment certainly contributed. However, the NAFO Scientific Council has generated its own estimates of 3M cod catches for the years from 1971, which suggest that nearly 29 000 tonnes were taken that year and more than 48 000 tonnes the next. The estimates fall from that point onwards, but still suggest that 10 000 tonnes were taken in 1995 (González-Troncoso, 2015). Though the fishery was closed for 1988–1990, official reports indicate, conversely, that landings increased from 1990, peaking at 8 300 tonnes in 1993 (mostly by Portugal, Spain and the Faroe Islands), before slowly declining again. Those reports were consistent with the TACs that were re-established from 1991 to 1998 (Figure 6.13).

However, recruitment failed after the 1991 year-class and biomass consequently collapsed, falling below 6 000 tonnes from 1996 (González-Troncoso, 2015); the directed fishery was therefore closed again from 1999. Reported landings of cod bycatches were under 100 tonnes for several years, while the Scientific Council's estimated catches dwindled to just 5 tonnes in 2004.

FIGURE 6.13
Reported landings and estimated catches of Atlantic cod from Division 3M for 1960–2017, showing landings by the principal flag states, STACFIS catch estimate and TAC



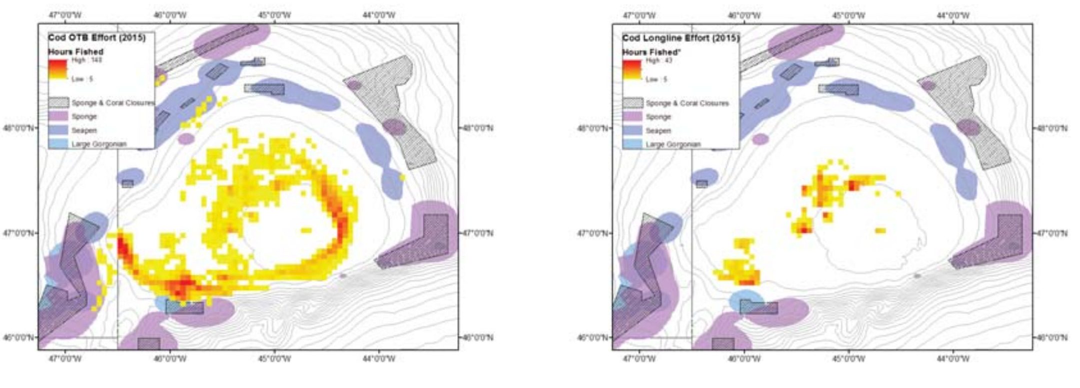
Source: STATLANT 21A and NAFO SC reports, NAFO website.

Almost uniquely for a high seas bottom-fishery resource, however, 3M cod recovered sufficiently for a directed fishery to reopen in 2010. The TACs rose from 5 500 tonnes that year to 14 521 tonnes in 2014, dipping slightly thereafter to 11 100 tonnes in 2018. Landings, by the directed fisheries, plus bycatches in redfish trawling, have risen along with the TACs. Vessels from Portugal, Faroe Islands and Spain have taken most of the catch, though several other flag states have participated, taking a total of 13 339 tonnes in 2016.

In more recent years, the 3M cod fishery is conducted with 130 mm mesh size bottom-trawl gear at depths between 150–550 m and mostly between 300–400 m, with the highest concentrations of effort in the southwestern and southeastern areas of the slope of the bank (Figure 6.14a). Cod comprised 92 percent of the catches with around 7 percent of redfish as bycatch. In actuality, the cod and redfish tend towards a mixed bottom trawl fishery. A longline fishery is also conducted for cod at 200–400 m in the northwest portion of the Flemish Cap along the slope of the bank (Figure 6.14b) with the principal bycatch being skate and Greenland shark (NAFO, 2016).

The resource has not yet recovered to the levels seen in the early 1970s, but is considered to be well above the minimum limit reference point of B_{lim}. However, given that the strong 2009–2012 year-classes have been followed by poor recruitment since 2015, this is likely to sharply reduce the spawning stock biomass in the medium term (González-Troncoso, 2015; NAFO, 2018a).

FIGURE 6.14
Atlantic cod bottom high seas fishing effort in Division 3M for 2015 for: (a) bottom otter trawl and (b) longline fleets and areas important for VMEs



(a) (b)

Source: Information from daily catch reporting and vessel monitoring system position reporting in NAFO, 2016.

Longline fishery for Atlantic halibut

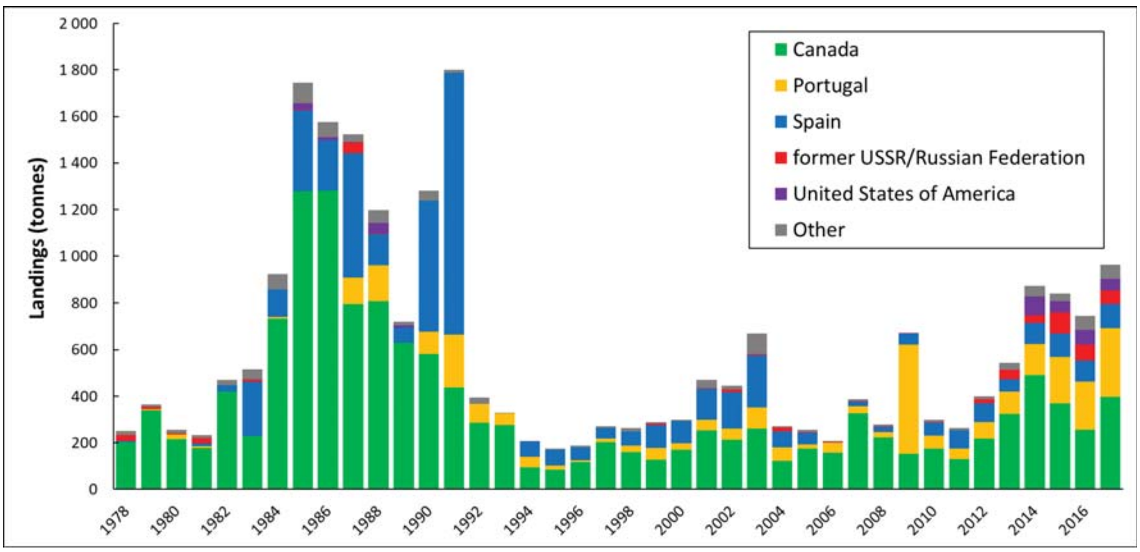
The fishery was at its peak when G.B. Goode and his colleagues prepared their monumental account of The Fisheries and Fishery Industries of the United States (Goode and Collins, 1887; Rathbun, 1887). The growth of urban seafood markets in the United States of America, with new railway links to fishing ports, stimulated the development of a fishery for fresh Atlantic halibut on Georges Bank, which began in 1830. The resource on the Bank declined swiftly after 1848 but the fleet expanded eastwards and northwards, aided by the adoption of ice for preservation of the catch on longer trips. The halibut fleet sequentially depleted its resource as it proceeded, "fishing down" the virgin biomass in each local area before moving on. The halibut schooners reached the last practical shallow ground for fresh fishing, the Southeast Shoal of Grand Bank, by 1870. From 1873, however, halibut were found to live deeper than had been supposed and, by 1881, they were fished on the continental slopes down to 750 m depth, as well as eastwards to the slopes of Flemish Cap (Goode and Collins 1887; Rathbun 1887).

The New England halibut industry had its last good year in 1921, with catches of more than 2 000 tonnes. From then, it declined steadily and ceased entirely after 1942. The growing North American economy allowed the price differential between halibut and cod to rise from 4.5 times in 1944 and to 8.5 times by 1953. The combination of catch rate and price drove a marked increase in effort and the Canadian halibut catch reached 6 000 tonnes in 1950, two-thirds of which was taken by the dory schooners. Annual catches then settled back to some 2 000 tonnes (McCracken, 1958). Motor longliners entered the deepwater fishery off Nova Scotia by the early 1950s (McCracken, 1958) and gradually replaced the schooners. By 1990, a small fleet of Nova Scotian longliners worked the continental slope from Georges Bank to Flemish Cap at depths down to 900 m (Kenchington *et al*., 1994; Kenchington, 1996).

The current directed Canadian halibut longline fishery is now regarded as a small-scale fishery for which NAFO does not set a TAC, and it is probably all taken within the Canadian EEZ. The long-term, average annual catch of Atlantic halibut by Canadian vessels from 1960 to 2012, all of which was likely taken within the Canadian EEZ, was 1 800 tonnes. Decadal averages of the annual catches taken by the directed fishery on the continental slopes around Grand Bank alone have varied between 500–1 000 tonnes since 1960 (den Heyer *et al*., 2015).

Atlantic halibut has been taken as a bycatch since 2000 in the high seas around the Grand Bank and Flemish Cap, in fisheries directed towards Greenland halibut, Atlantic redfish, yellowtail flounder or mixed groundfish. These fisheries are exploited with bottom otter trawls, mainly by Spain and Portugal. The United States of America has had a small directed fishery for Atlantic halibut since 2014. The total high seas catch in this area, assuming that Canadian catches are from the Canadian EEZ and other states are from the high seas, ranges from 52 to 1 364 tonnes per year, with an average of 250 tonnes each year for 1977–2016 (Figure 6.15). The non-Canadian catches for 1978–2017 were 43 percent from Division 3N, with the remainder divided equally between Divisions 3L, 3M and 3O. The Canadian catches are from Divisions 3L, 3N and 3O, all of which straddle the EEZ/high seas boundary.

FIGURE 6.15
Landings of Atlantic halibut from Division 3KLMNO since 1978



Canadian catches probably from within Canadian EEZ, and others from the high seas.
Source: STATLANT 21A and NAFO SC reports, NAFO website.

Bottom and deep midwater trawl fisheries for redfish

The long-lived North Atlantic redfish, the various species of which are not distinguished by the seafood trade and cannot be efficiently harvested with hooked gears. Their quality deteriorates relatively rapidly when held on ice, while their proportion of edible flesh is only around one third by weight, which is considerably lower than with gadoids. Substantial directed fisheries for them, at least those supplying North American markets, therefore had to wait for the adoption of otter trawling and the market's acceptance of fillets, which were adopted by the New England seafood trade from the 1920s (Lear, 1998). Other developments, such as that of freezing technology and the expansion of refrigeration throughout the seafood marketing chain, into retail stores and private homes, further increased its exploitation.[8]

New England redfish trawling initially harvested Acadian redfish in the Gulf of Maine at 100–300 m depth. Landings were recorded as early as 1916 but rarely exceeded 100 tonnes in any year before 1934, when the various prerequisites finally came into place. Catches by the United States of America reached 30 000 tonnes in 1936. Landings from Georges Bank and the western side of the Gulf (SA 5) peaked at 60 000 tonnes in 1941 but then fell away with the advent of war (Côté, 1952; Mayo, 1980). After 1945, the fishery moved to the Scotian Shelf and then on to the Gulf of St. Lawrence. Landings from those areas combined (SA 4) peaked at over 80 000 tonnes in 1951.

The Canadian trawling industry had been tightly constricted by regulation prior to 1939 (Balcom, 1997), keeping national redfish catches low. Newfoundland trawlers expanded the redfish fishery in SA 3 from 1947, with mainland Canadians following soon after (Côté, 1952). In that subarea, the resource includes a higher proportion of deeper-dwelling beaked redfish and golden redfish. As it expanded, trawling therefore moved down the continental slope, sometimes to 400 m depth (Martin, 1961). Fishing locations were not recorded with any spatial precision finer than NAFO divisions and hence the beginning of redfish trawling in the modern high seas cannot be dated with certainty. However, landings from Division 3N were reported from 1953 onwards and, since the redfish grounds were primarily along the shelf break and on the slope, those catches were very probably made outside what is now Canada's EEZ. Canadian redfish trawlers, most of them working out of Newfoundland, thus initiated the high seas fishing for deep long-lived resources; half a century later this would eventually become a policy issue of international concern.

Research and scouting vessels from the former USSR explored the Grand Banks from 1954 (Marti, 1962). The first two of their new factory-freezer stern-trawlers (near-copies of the British *Fairtry,* carrying onboard filleting and freezing capability) followed in 1956, initially fishing Flemish Cap and taking 13 000 tonnes of redfish and 4 000 tonnes of other species. Full-scale fleet operations began the following year, when catches by the former USSR in SA 3 reached 49 000 tonnes of redfish, 18 000 tonnes of cod and 2 000 tonnes of other species, most of which were again taken on Flemish Cap. By the mid-1960s, the former USSR was sending more than 100 stern-trawlers and 400 side-trawlers (which off-loaded to "mother ship" factories) to the northwest Atlantic. They had already severely depleted the redfish and increasingly turned to continental-shelf species and to the deep-living roundnose grenadier (Rose, 2007).

The demersal redfish fisheries in the NRA and adjacent Canadian waters came to be managed as three units, in Division 3LN, Division 3M and Division 3O respectively, though in each case the two or three nominal species present were combined (as they continue to be).

[8] Clarence Birdseye's multiplate freezer, first brought into service in 1933, was developed in Gloucester, Massachusetts for freezing redfish fillets.

Divisions 3LN redfish

The 3LN redfish occur mainly on the eastern continental slopes of the nose and tail of the Grand Bank at 200–600 m depth (Figure 6.16a).[9] From 1960 until the mid-1980s, the Division 3LN unit yielded catches of 8 000–33 000 tonnes annually (Figure 6.17). The former USSR dominated that fishery almost throughout its history, though trawlers from the United States of America and Germany were also important in the early 1960s. When Spain and Portugal joined the European Union in 1986 there was the same setting of unilateral redfish quotas based on the F_{max} criterion as for cod fisheries (Barry *et al*., 2014). A Portuguese fleet entered the Division 3LN fishery that same year, driving effort and catch upwards – the latter to a peak of 71 000 tonnes in 1987. Thereafter, trawlers from Portugal, the former USSR (later the Russian Federation and Latvia) and the Republic of Korea were responsible for most of the redfish landings from the two divisions up to 1993. However, catch rates, which had been falling rapidly since the peak years, fell further from 1994 onwards as the fishery collapsed and most of the few redfish taken were bycatch in Greenland halibut trawling. TACs were first set by NAFO in 1974 and were followed reasonably well until the mid-1980s when catches were double the set limits. However, even though TACs were sharply reduced thereafter, they could not halt the declining redfish population: a moratorium on directed redfish fishing covering the two divisions was thus declared from 1998 (Ávilade Melo *et al*., 2014). The officially reported catches by member countries were in close agreement with scientific estimates for most years; though they show that catches may have been higher than reported in the early 1990s, when the stock was declining. How much of the fishing had been in what are now high seas is uncertain, but it probably included the majority of it after 1980 and perhaps ever since the fishery reached Division 3N in 1952.

The moratorium on directed redfish fishing in Division 3LN, imposed in 1998, lasted until 2009. A small TAC was re-established for 2010 and was raised steadily to 14 200 tonnes for 2018 as the stock recovered. Catches have increased similarly (Ávila de Melo *et al*., 2014). In 2016, Division 3LN redfish catches included 2 972 tonnes by the Russian Federation and 2 057 tonnes by Portugal, the two flag states that have dominated the distant-water fishery since it reopened. There were also Canadian catches of 2 822 tonnes but essentially all of them were taken within that state's EEZ. In 2016, the high seas catch from Division 3LN, across vessels of all flags and including bycatch, was 5 804 tonnes. The 2016 TAC was 10 400 tonnes; of these, 5 970 tonnes was allocated as quotas to distant-water states, and the rest to Canada (NAFO, 2017). This is because this is a transboundary management unit and Canada receives 42.6 percent of the allocation for its EEZ waters. The TAC was increased by almost 4 000 tonnes in 2017 and catches increased accordingly by around 3 000 tonnes.

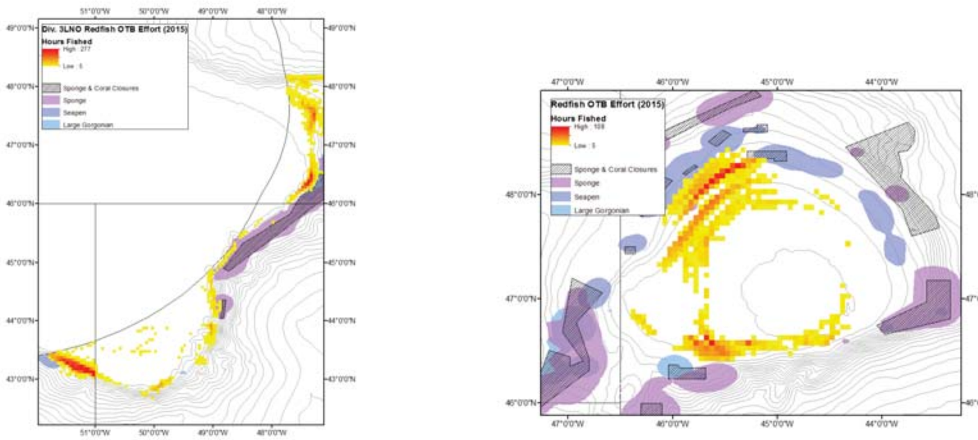
Division 3M redfish

The Flemish Cap 3M redfish are fished at 200–600 m depth around the slopes of the Flemish Cap with the highest catches occurring on the northwest side (Figure 6.16b).[10] From its inception in 1956 until the mid-1990s, the Flemish Cap fishery was highly variable, driven in part by the irregular recruitment for which redfish are renowned (Figure 6.18). Annual catches dropped to near zero in 1967, when the former USSR fleet withdrew from the fishery for the year (turning to roundnose grenadier and hake on the Patagonian Shelf), but recovered to around 20 000 tonnes annually through the 1970s and into the 1980s. Aside from 1967, the former USSR dominated the

[9] This resource is comprised of the deep-sea redfish (*Sebastes mentella*) and the Acadian redfish (*Sebastes fasciatus*), collectively known as beaked redfish.

[10] This resource is comprised of deep-sea redfish (*Sebastes mentella*), Acadian redfish (*Sebastes fasciatus*), and golden redfish (*Sebastes norvegicus* (=*S. marinus*)). The term beaked redfish is used for *S. mentella* and *S. fasciatus* combined.

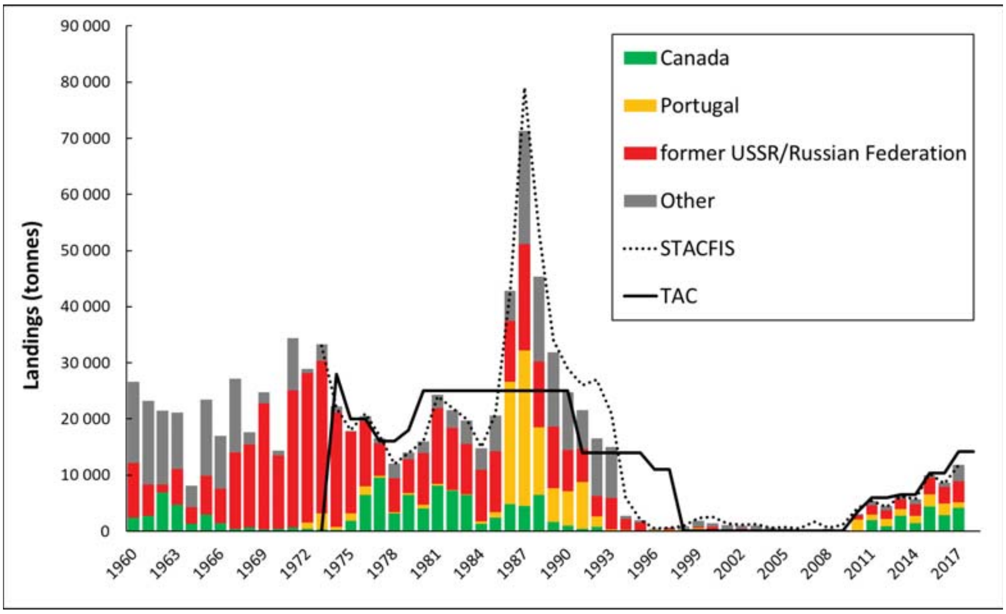
FIGURE 6.16
Redfish bottom high seas trawl fishing effort for 2015 in:
(a) Division 3LNO and (b) Division 3M and areas important for VMEs



(a) **(b)**

Source: Information from daily catch reporting and vessel monitoring system position reporting in NAFO, 2016.

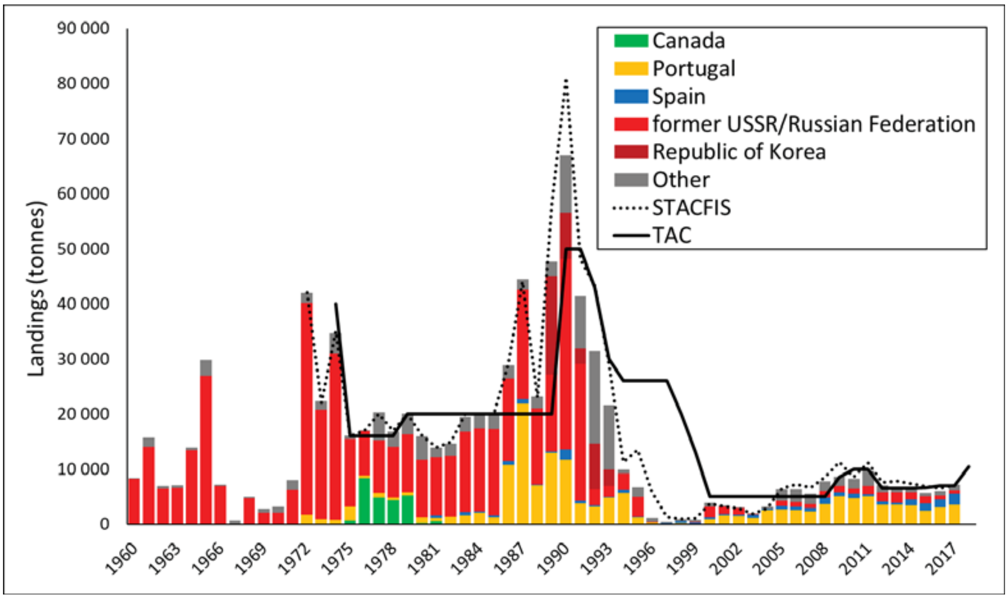
FIGURE 6.17
Landings of redfish in Division 3LN since 1960, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

fishery until 1985. The Portuguese fleet then took a major role, while trawlers from the Republic of Korea joined the fishery three years later, driving catches upwards to reach either 67 000 tonnes (NAFO STATLANT 21A database) or 81 000 tonnes (Ávila de Melo *et al*., 2013) in 1990. The same three states continued to dominate through to 1995, except that the former USSR was replaced by Estonia, Latvia and the Russian Federation as separate entities. However, falling biomass drove catches down after 1990 and probably ended directed redfish trawling on Flemish Cap from 1996. The TAC was cut to 5 000 tonnes in 2000, though adult redfish were then little more than

FIGURE 6.18
Landings of redfish in Division 3M since 1960, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

a bycatch of the Greenland halibut fishery, while many juveniles were taken by shrimp trawlers (Ávila de Melo *et al.*, 2013).

The resource and the fishery recovered somewhat after 2004, providing catches of 6 000–11 000 tonnes from 2006 onwards, though some was bycatch taken by the renewed cod fishery. In recent years, the largest catches have been taken by Portuguese vessels, while trawlers under Russian, Estonian, Spanish and other flags have also been active (Ávila de Melo *et al*., 2013). In 2016, 3M redfish catch was 5 970 tonnes, against a TAC of 7 000 tonnes.

Division 3O redfish

The 3O redfish fishery is on the slopes of the western edge of the tail of the Grand Bank at 200–600 m depth (Figure 6.16a) and is taken by Canada within its EEZ and by distant-water fleets in the high seas.[11] Management has been primarily under Canadian control with a TAC set from 1974 and a minimum size limit of 22 cm from 1995. NAFO adopted a TAC from 2005 that applied to the whole stock.

The 3O redfish fishery was usually smaller than the other two management units up until the late 1990s, typically landing 5 000–20 000 tonnes annually, with the NAFO Scientific Council estimating a peak catch of 35 000 tonnes in 1988 (Ings *et al.* 2013)[12]. Catches soon dropped back to normal levels, but the decline in the NAFO 3LN and 3M redfish made the resource in Division 3O the most important of the three during the latter half of the 1990s. From the early 1960s until 1993, that fishery was dominated by the former USSR fleets (subsequently the Russian Federation). Since then Portuguese trawlers have usually taken the largest share of each year's catch, though Canadian, Spanish and Russian vessels have also been important at times. The redfish grounds in the Division are largely in waters now under national jurisdiction but the sizes of the fish were generally too small to have great interest for the Canadian industry.

[11] Comprises of the deep-sea redfish (*Sebastes mentella)* and the Acadian redfish (*Sebastes fasciatus*), collectively known as beaked redfish.

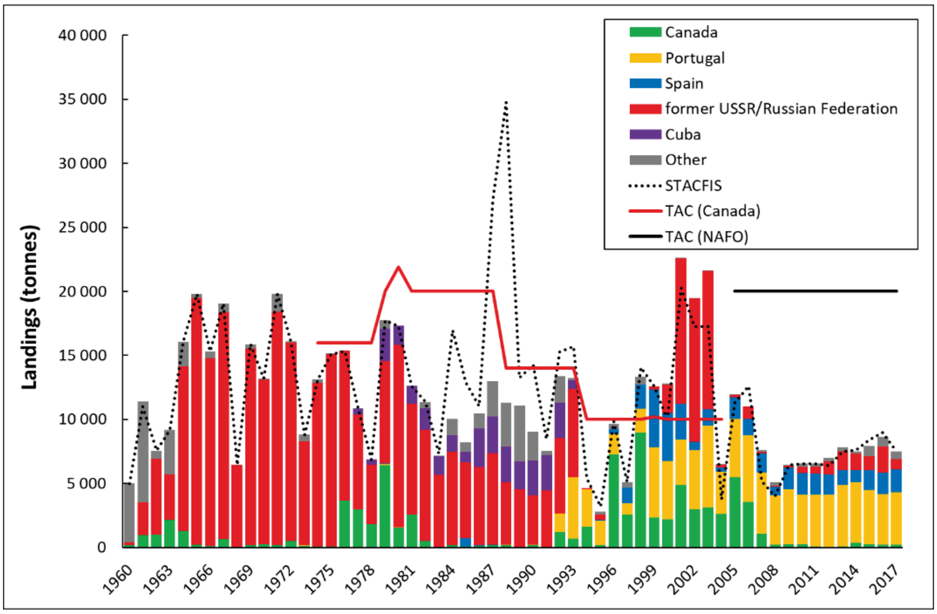
[12] The NAFO STATLANT 21A database does not show an annual catch of Division 3O redfish greater than 18 000 tonnes between 1972 and 1999.

Thus, until 1993, much of the catch was taken by trawlers from the former USSR (subsequently the Russian Federation) working in the Canadian zone under access agreements, with similar arrangements for Cuba and Japan. Those arrangements ended in 1994 (Ings *et al*., 2013). The proportion of subsequent catches taken in the high seas is unclear (Figure 6.19).

Catches in Division 3O rose to a high of 20 400 tonnes in 2001 against a TAC of 10 000 tonnes, half of it taken by Russian trawlers and the rest by Canadian, Portuguese and Spanish vessels. The Russia Federation fleet largely withdrew after 2003, while Spanish and Canadian catches declined, but the Portuguese fishery continued (Ings *et al*. 2013). In 2016, 3O redfish catches amounted to 8 624 tonnes, while the fishery under national jurisdiction had faded to only 210 tonnes, all of which was likely bycatch. The total high seas catch in 2016 was therefore 8 416 tonnes against a TAC of 20 000 tonnes).

All reports, to NAFO, of redfish catches taken in recent years have specified the gear used as bottom trawls, except those taken under the Russian and Latvian flags, which were all reportedly taken by midwater trawl around 2000–2004. Russian Federation midwater trawl catches were 629–2 866 tonnes in this period, with an additional midwater trawl catch of 1 036 tonnes in 2016. The Canadian EEZ fishery records around 93 percent taken with bottom trawls between 1992 and 2011, with the balance made of up midwater trawls used in the earlier years (Ings *et al*., 2013).

FIGURE 6.19
Landings of redfish in Division 3O since 1960, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website; TACs and estimates from Ings *et al*., 2013.

Bottom trawl fishery for haddock

Unlike redfish, haddock can be efficiently caught by longline but, contrary to Atlantic cod, they do not salt well, while few North American consumers developed a taste for the Scottish alternative of a smoked product. Thus, the haddock fisheries of the northwest Atlantic did not develop until evolving consumer tastes, icing and railway transport allowed the growth of a fresh fish trade. The United States of America, which had exploited the resource off its own shores from the nineteenth century, reported landings from SA 3 beginning in 1902. The haddock fishery in that subarea was really developed by Newfoundlanders in the 1930s, who could land the fish fresh. Recruitment has varied considerably and the fishery is dominated by the presence of strong year-classes. During the 1950s catches by Spain and Canada in SA 3 peaked at 104 000 tonnes in 1955, while in the followed decade the former USSR and Canada reported landings from Division 3LMNO of 77 000 tonnes in 1961 (Hodder, 1966; Templeman *et al*., 1978). However, catches outside of these peak years were much reduced, dropping below 10 000 tonnes annually after 1963, and below 1 000 tonnes after 1975 (Figure 6.20a). In the late 1950s and early 1960s, the haddock were distributed near the tail of the Bank, straddling across what is now the boundary of Canada's EEZ (Rose, 2007).

The loss of the Grand Bank haddock was a classic example of recruitment overfishing – encouraged, in part, by a few strong year-classes produced as the resource was depleted. However, low spawning biomasses were not solely responsible for the poor recruitment after 1955: the marked cooling during most of the 1950s and 1960s also had an impact on the resource (cf. Templeman *et al*., 1978; Rose, 2007), which was at the northern limit for its species. Moreover, the once-important haddock resource in the southern Gulf of St. Lawrence declined at the same time as that on Grand Bank, without large catches being taken, and has never recovered (Kenchington, 1996); this suggests that environmental factors exerted a powerful influence on the resources.

There was a brief recovery of 3LMNO haddock catches from 1984 to 1992, and to a lesser extent around 2003 and from 2010 to the present, where catches increased around the nose and tail of the Grand Bank and on Flemish Cap, taken mainly by Spain and Portugal (Figure 6.20a). Catches in the high seas, obtained by removing Canadian catches from the series, peaked at 173 tonnes in 2003 and 366 tonnes in 2014, with some 32 percent coming from the Flemish Cap (Figure 6.20b). Haddock are taken mainly as bycatch by bottom set longline and bottom trawl fisheries targeting a wide range of other species. High seas catches, presumably all bycatch and largely taken by Spanish vessels, amounted to 225 tonnes in 2016.

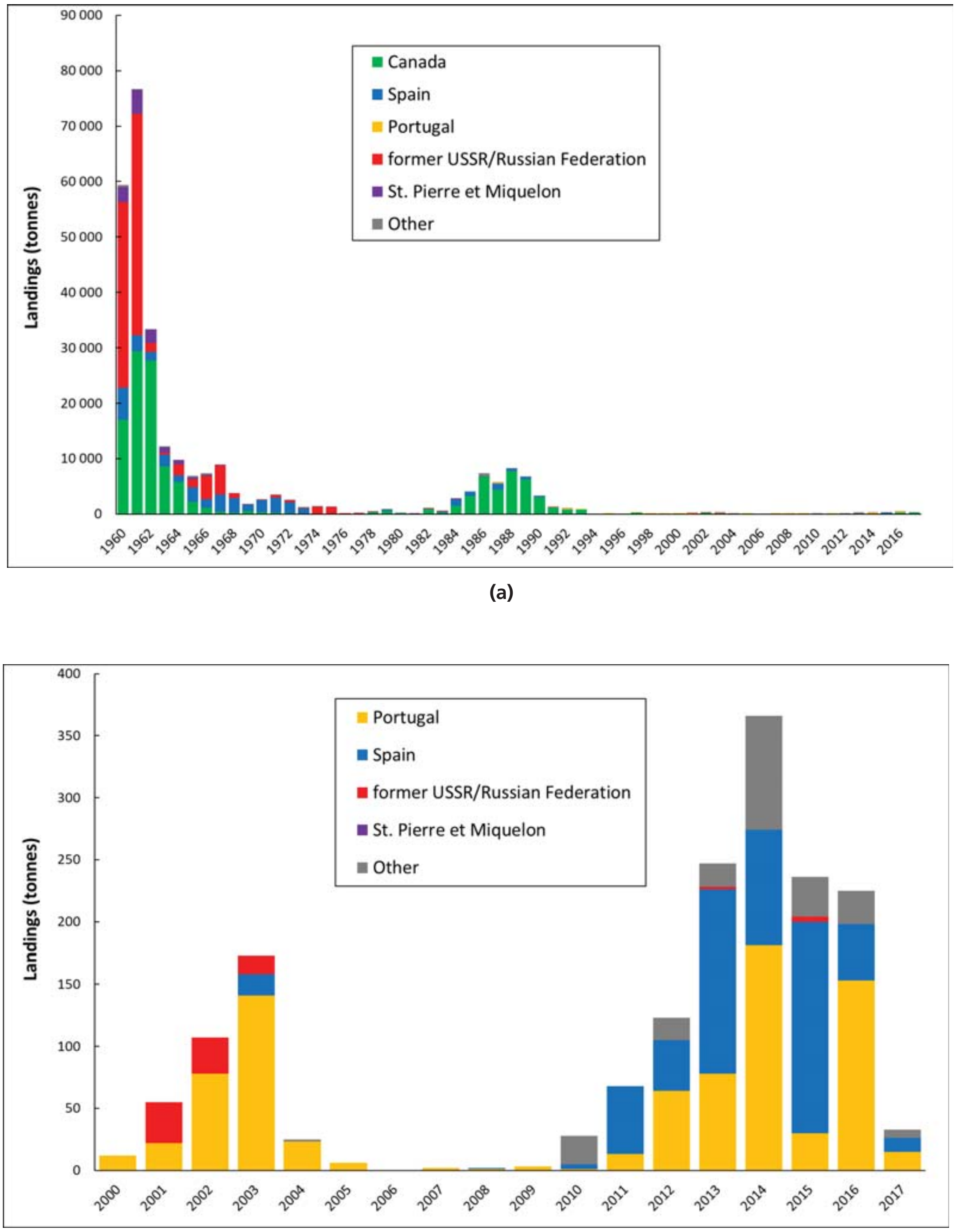
Bottom trawl fisheries for flounders

Three species of flounders have supported directed bottom trawl fisheries on the Grand Banks: American plaice, witch flounder and yellowtail flounder. The early catch data did not separate the three (nor were the later separations fully reliable), while those data were published with no higher spatial precision than NAFO subarea. However, when first separated by species, in 1960, the SA 3 landings were approximately three-quarters American plaice and one-quarter witch flounder, with only a few tonnes of yellowtail flounder. When the data were first presented with a spatial precision of NAFO Division, in 1954, the landings from Divisions 3L, 3N, 3O and 3P were roughly equal, meaning that three quarters came from Grand Bank.[13] However, 3LN flounder cannot be assumed to have come from the modern NRA and there is no reason to suppose that the earliest catches in those divisions were taken in what are now the high seas.

Vessels from the United States of America, with their ready access to urban markets, had begun landing flounders from SA 5 before 1900, as Canadians did from SA 4 in 1911. However, neither fleet landed more than a few tonnes from SA 3 until much later. Newfoundlanders started landing flounders from off their own coast in 1941 and, with the emergence of their trawler fleet and filleting plants, landed more than 1 000 tonnes annually from 1948 onwards. Canadian trawlers expanded into SA 3 from 1942 but only surpassed 100 tonnes of flounder in a single year in 1948. Vessels from the United States of America also landed some that year but did not commence a commercial-scale

[13] Information from ICNAF *Statistical Bulletins* for 1951–60.

FIGURE 6.20
Reported landings and estimated catches of haddock from Division 3LNO between (a) 1960 and 2017, and (b) detail for 2000–2017, showing landings by the principal flag states



(b)

Source: STATLANT 21A and NAFO SC reports, NAFO website.

fishery until 1950 (Côté, 1952). It is very likely that fishermen under other flags, and in earlier years, caught and discarded some flounders but there are no records of landings.

The SA 3 flounder landings rose steadily through the 1950s, those from Division 3LNO reaching 20 000 tonnes in 1957 and remaining at that level to the end of the decade. The overwhelming majority of the catch was taken by Canadian (including Newfoundland) vessels. The smaller landings made under other flags, which were presumably bycatches, became more frequent from 1957, when the factory-freezer trawlers arrived and it became viable to preserve the small flatfish on board for longer than required to land them on the adjacent coast.[14]

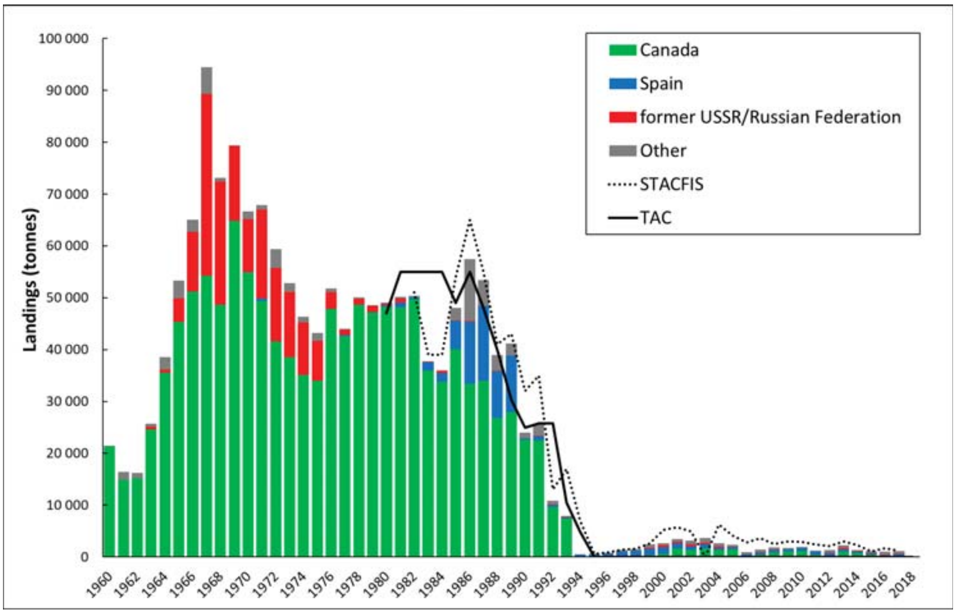
American plaice

There are two stocks of American plaice fished in the high seas: the Grand Bank 3LNO stock that straddles the Canadian EEZ, and the Flemish Cap 3M stock. These two stocks are both managed by NAFO and were closed to directed fishing in 1994 and 1996, respectively. Current catches are from bycatches in other trawl fisheries.

Canadian landings of American plaice from Division 3LNO were around or above the 30 000 tonnes level for 1965–1989. These were supplemented by distant-water former USSR trawlers from 1965 to1975. In 1985, Spanish trawlers increased their catch of 3LNO American plaice. The following year the European Union, by setting its unilateral quotas based on F_{max} (Barry *et al.*, 2014), enabled the reported distant-water catch to reach 24 000 tonnes, in addition to 33 000 tonnes reported by Canada, though the NAFO Scientific Council believed they were higher, at almost 65 000 tonnes (Figure 6.21; Dwyer *et al.*, 2012). Catches declined thereafter and directed fishing was prohibited in 1994, with the TAC set to zero the following year. How much of those catches were taken in the modern high seas is unclear, but the major concentration of American plaice is now on the high seas part of the tail of the Bank, and it is likely that much of the American plaice taken in earlier decades was caught there (Dwyer *et al.*, 2012).

Bycatches of 3LNO American plaice continued, however, and Scientific Council estimated that they rose steadily to 8 700 tonnes in 2003, taken by the fisheries for yellowtail flounder, thorny skate, redfish and Greenland halibut (Dwyer *et al.*, 2012). Annual catches of 3LNO American plaice in the high seas have declined steadily since 2003 and have been a little over 1 000 tonnes in recent years. The resource has not recovered during the two decades of closure, mainly due to poor recruitment since

FIGURE 6.21
Landings of American plaice in Division 3LNO since 1960, STACFIS catch estimate and TAC



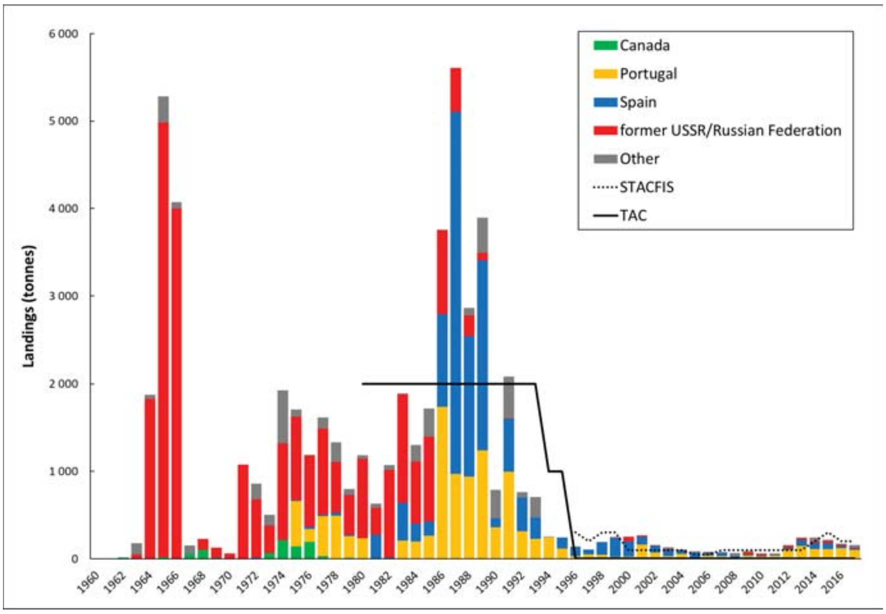
Source: STATLANT 21A and NAFO SC reports, NAFO website.

[14] Data from ICNAF *Statistical Bulletins* for 1951–60.

the 1980s. Currently the fishing mortality is estimated to be very low and there are indications from surveys of increasing pre-numbers providing a more optimistic view (Dwyer *et al*., 2012; NAFO, 2018a).

The Flemish Cap fisheries for American plaice have been much smaller than those on Grand Bank. Landings began with a few hundred tonnes of generalized flounder bycatch in the former USSR redfish fishery, from 1957, with Portugal and Spain joining the fishery in the 1970s and 1980s.[15] Very high catches occurred in 1964–1966 and 1986–1989 peaking to over 5 000 tonnes on both occasions (Figure 6.22). Catches then started to decline and since 1991 annual landings have been below 1 000 tonnes. The directed fishery has been closed since 1995 and bycatches were under 100 tonnes per year from 2004 to 2010 (Alpoim *et al*., 2011). In recent years, with the reopening of the Atlantic cod resource leading to increased trawling effort on the Cap, bycatches have been around the 200-tonne level. The stock has shown some marginal improvement in recent years with better recruitment since 2009, though the stock remains at a low level and in poor condition.

FIGURE 6.22
Landings of American plaice in Division 3M, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

Witch flounder

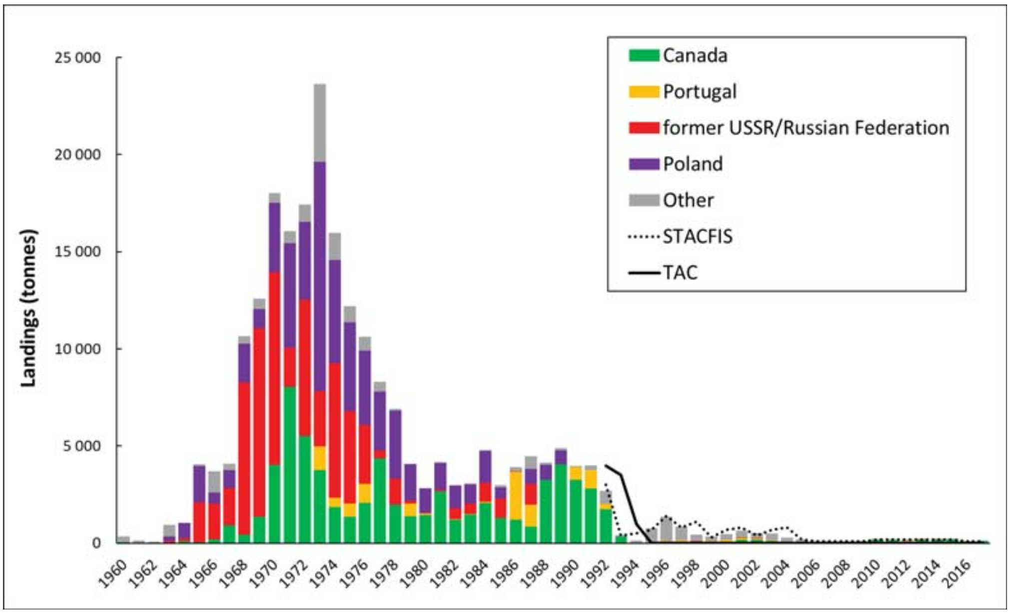
The witch flounder on Grand Bank are managed as parts of two units, Division 2J3KL and Division 3NO respectively, the latter of which accounts for most high sea catches. There is a small catch from the Flemish Cap, but this is not managed. The 2J3KL and 3NO fisheries were closed in 1995 and 1994 respectively.

Most of the 2J3KL witch flounder management unit are found in Division 3K and hence in the Canadian zone. Small landings, probably bycatches, were reported from 1960 but they did not reach 1 000 tonnes until 1964, when Poland and the former USSR dominated the fishery. The total catch reached 18 000 tonnes in 1970, more than half taken by former USSR trawlers, and most of the rest by Canada and Poland. Catches by the former USSR then declined, but Polish trawlers took more, raising the overall catch to a record 24 000 tonnes in 1973, after which there was swift decline. In the

[15] Data from ICNAF *Statistical Bulletins* for 1951–60.

1979–1992 period, annual catches stabilized at 2 700–4 900 tonnes. The Canadian directed fishery was closed in 1993, though bycatches of up to a few hundred tonnes continued. NAFO set a zero TAC from 1995, when biomass was less than 2 percent of what it had been in 1984, though there have been bycatches of up to 1 400 tonnes per year (Figure 6.23). While the spatial distribution of the directed fishery is poorly known, distant-water vessels, trawling in the NRA, have been responsible for much of the catch since the mid-1990s (Maddock Parsons, 2013). Annual catches of 3L witch flounder in the NRA during 2012–2015 ranged from 35 to 198 tonnes.

FIGURE 6.23
Landings of witch flounder in Division 2J3KL, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

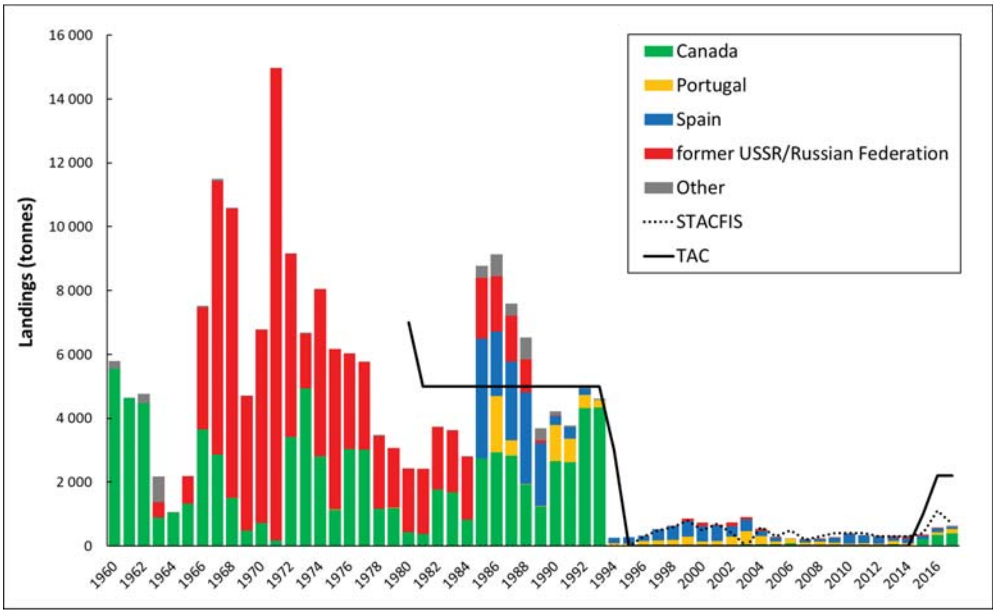
The 3NO witch flounder landings for 1960–1993 fluctuated at around 1 000–14 000 tonnes, taken largely by Canada, the former USSR, and Spain. However, with the resumption of higher catches and an increasingly unfavourable environment, biomass declined sharply into the 1990s (Figure 6.24). The Canadian directed fishery was closed in 1993, leaving only small bycatches. NAFO terminated directed fishing from the following year, though bycatches in the NRA have been in the hundreds of tonnes. In contrast to American plaice, the witch flounder resource has responded positively and biomass has approximately doubled since the closure. A new 1 000 tonnes TAC was instituted for 2015, reopening a minimal directed fishery (Lee *et al*., 2015). NAFO estimates of annual catches of 3NO witch flounder in the NRA during 2012–2015 have been 175–327 tonnes annually.

Witch flounder were landed from Division 3M as bycatch in the bottom trawl fishery during 1986–2005, averaging nearly 500 tonnes annually. Catches are currently around 200 tonnes per year.

Yellowtail flounder

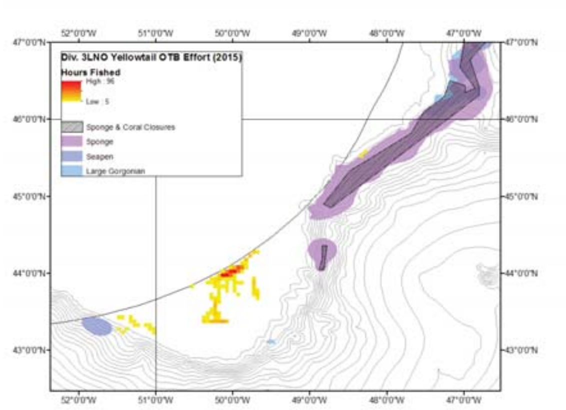
Yellowtail flounder is a shallow-dwelling species typically caught above 200 m depth, broadly distributed across Grand Bank, including in the high seas towards the tail of the Bank (Figure 6.25). Yellowtail flounder do not occur on Flemish Cap (Brodie *et al*., 2010). A distant-water fishery emerged in the mid-1960s, with Canadian trawlers joining later. Catches from Division 3LNO grew swiftly after 1968 and peaked at

FIGURE 6.24
Landings of witch flounder in Division 3NO, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

FIGURE 6.25
Yellowtail bottom high seas trawl fishing effort for 2015 in Division 3LNO, and areas important for VMEs

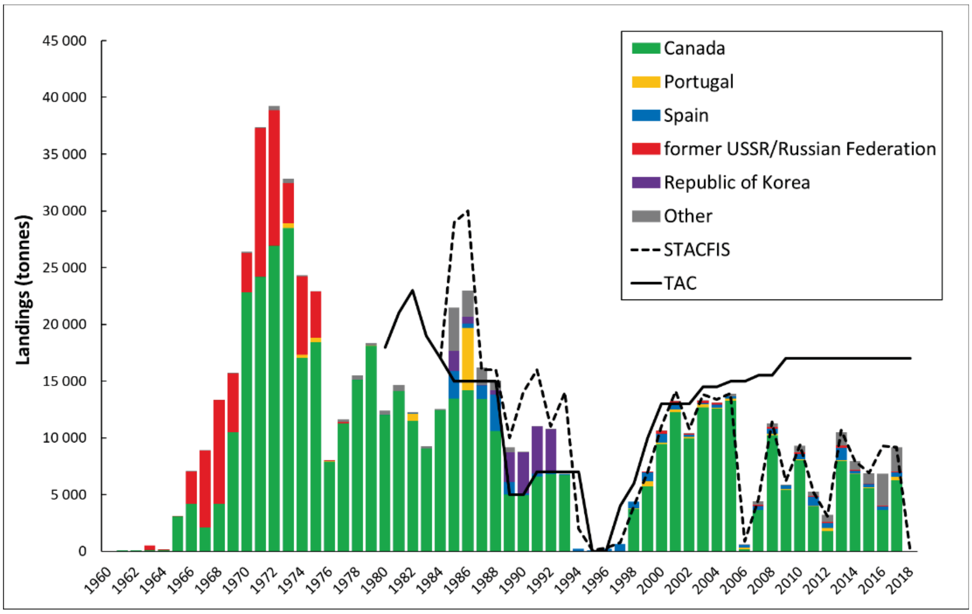


Information from daily catch reporting and vessel monitoring system position reporting.
Source: NAFO, 2016.

39 000 tonnes in 1972 (Figure 6.26). Annual catches in the 10 000–30 000 tonnes range continued thereafter, as biomass fell into the mid-1970s. ICNAF and, subsequently NAFO, set TACs from 1973 but the early ones were non-restrictive and effective constraint on catch only began in 1976. In all, 97.5 percent of the NAFO TAC was allocated to Canada, leaving little for the distant-water states (Brodie *et al*., 2010).

From 1986, the unilateral quota setting imposed by the European Union (Barry *et al*., 2014) led to much larger catches than the TACs allowed, more than doubling the already high fishing mortality, with a resulting plunge in biomass to very low levels by 1994. The directed fishery was then closed and landings reduced to bycatches of some hundreds of tonnes each year, mostly taken by the thorny skate fishery. Unlike

FIGURE 6.26
Landings of yellowtail in Division 3LNO, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

the other flounder species, the yellowtail flounder resource recovered very quickly, driven by a sequence of strong year-classes that had already been spawned before the moratorium was implemented and which were protected from fishing while they were juveniles. The directed fishery was reopened in 1998, under TACs that were low relative to the existing biomass, allowing a further increase in the resource (Brodie *et al*., 2010). The greater part of the TAC has continued to be allocated to Canada and a significant amount has therefore been caught within the EEZ.

National catches grew to 13 000 tonnes in 2005 but have been much lower since. Meanwhile, approximately 1 000 tonnes per year has been landed by vessels under various other flags, presumably all taken in the high seas. In 2016, NAFO recorded catches of 3 657 tonnes by Canada, 1 359 tonnes by Japan, 897 tonnes by the United States of America, 288 tonnes by Spanish trawlers, 80 tonnes by the Russian Federation, 13 tonnes by Portugal, and 351 tonnes by Estonian vessels, to a total of 6 826 tonnes. Some of those were so small as to suggest that they were actually bycatches. The Division 3LNO catch in the high seas was 4 362 tonnes (NAFO, 2017b); this difference resulted from Canada's catch within its EEZ. The quota allocations were 16 575 tonnes for Canada, 340 tonnes for France (St. Pierre et Miquelon), and 85 tonnes to others. The variety of countries fishing this species arises from quote transfers and sharing.

Bottom and deep midwater trawl fishery for grenadiers

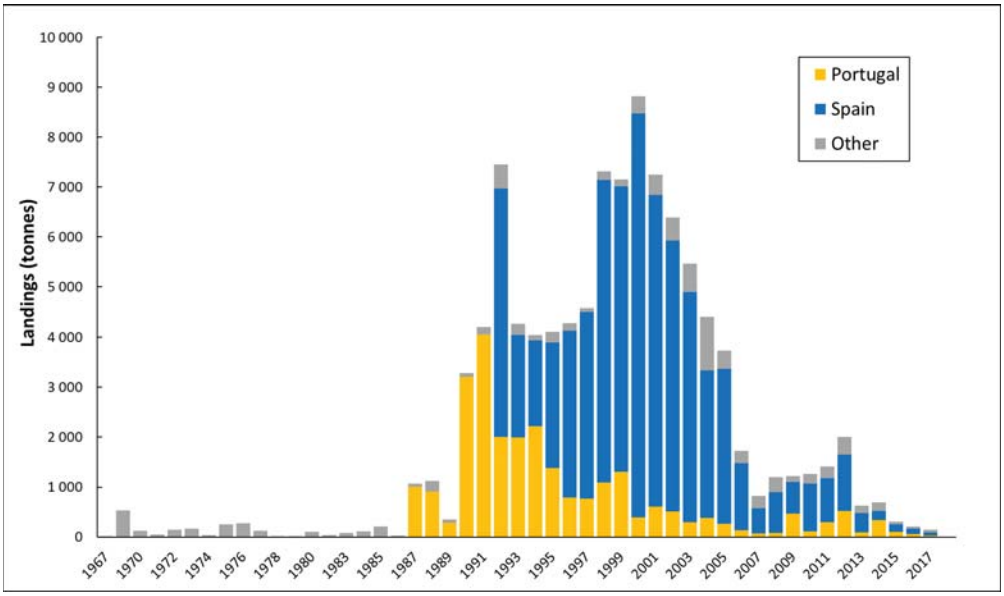
There has been, and probably still is, confusion about the identity of the grenadiers being caught in SA 2 and SA 3, and it is now believed that the majority are roughhead grenadier and not roundnose grenadier as previously reported to NAFO (NAFO, 2018a). The species is simply referred to as grenadier below. For assessment purposes, catches from SA 2 and SA 3 are considered as coming from single stock.

Commercial aggregations of grenadier were found at 500–1 700 m depth in the north, off Labrador and Baffin Island, within what is now the Canadian EEZ (SA 2 and Division 3K). Peak catches were nearly 84 000 tonnes in 1971 but declined in this area over the following two decades, and the directed fishery ceased in 1991. The bulk of the catch was taken by bottom trawling, though some midwater trawling was used where seabed conditions discouraged the use of bottom gear (Atkinson, 1995; Power and Maddock Parsons, 1998; Power, 1999; Shibanov and Vinnichenko, 2008).

The 3LMNO grenadier fishery started around 1986 and seemed to be limited to the deep trawling grounds of the Flemish Pass, as bycatch of the Greenland halibut fishery, which exploits a similar depth range and various other groundfish fisheries. The latter were initially fished by Portugal and more recently by Spain (Figure 6.27). Catches rose quickly to nearly 9 000 tonnes in 2000, then declined steadily, recovering a little around 2013; they are now at low levels with just 209 tonnes reported in 2016 and slightly less in 2017.

The state of the whole stock in SA 2 and SA 3 appears to be uncertain due to biomass surveys being apparently contradictory. They also do not appear to correspond with the declining catches seen in the fishery, or the fact that grenadier fishing mortality is low (NAFO, 2018a).

FIGURE 6.27
Landings of grenadier (roughhead and roundnose combined) in Division 3LMNO



Source: STATLANT 21A and NAFO SC reports, NAFO website.

Gillnet and bottom trawl fisheries for Greenland halibut

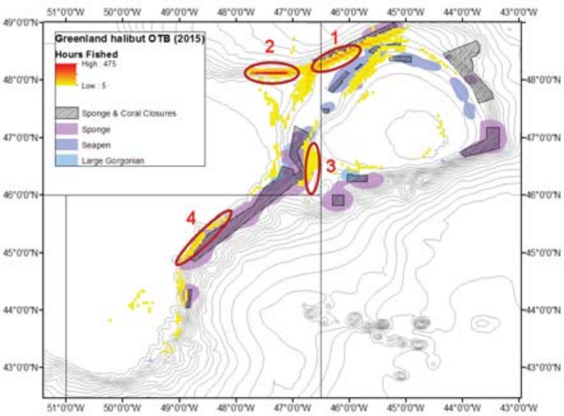
Newfoundland inshore fisheries have taken Greenland halibut (known to the Canadian fishing industry as "turbot") since the nineteenth century, following an earlier development by Greenlandic fisheries that started in their coastal waters. The advent of monofilament gillnets in the 1960s promoted the rapid development of a fishery in deep bays off the coast of Newfoundland. Catch rates in each bay fell swiftly and the all too familiar pattern of sequential depletion and geographic expansion was repeated. Eventually, the fishery moved out to deep channels between the coast and the offshore banks. During the late 1980s, with conventional groundfish resources declining, the Government of Canada encouraged exploitation of the Greenland halibut further north, off Labrador and in the Davis Strait. Distant-water trawlers also started to fish in the high seas between Flemish Cap and Grand Bank, initially working at depths down to 1 500 m, though some vessels were equipped to fish as deep as 2 000 m. (Bowering and Brodie, 1995; Iglesias and Paz, 1995; Healey, 2011). The resulting pressure on the resource, and the consequent disagreements over conservation limits led, in 1995, to conflict between Canada and Spain known as the "Turbot War" (see Soroos, 1997).

The effects of that confrontation contributed to adoption of the UN Straddling Stocks Agreement later the same year and led to more rigorous management within NAFO.

The high seas Greenland halibut fishery is managed as a widely distributed stock covering SA 2 and Division 3KLMNO. The fishery principally uses bottom otter trawls at 800–1 400 m depth, with four principal areas identified through an analysis of trawl position data and daily catch records (Figure 6.28). Some gillnet and longline gears are also used. TACs were set by Canada from 1874–1994, and then by NAFO thereafter. Catches have been dominated by Canada, taken predominantly – and no doubt exclusively – within their EEZ in the last 30 years. Foreign fleets, particularly Spain and the former USSR/Russian Federation, as well as Portugal to a lesser extent, have also taken considerable catches – initially over the whole stock area, and thereafter from the high seas as jurisdictions were cemented. Catches from this stock have been consistently high, with reported catches of around 15 000–58 000 tonnes annually (STATLANT 21A). For this stock and species, reported catches in the early 1990s and 2000–2014 were consistently lower – by some 35 percent – than those estimated by the NAFO Scientific Council, though this discrepancy did not occur for 2015–2017 (NAFO, 2018a). This means that catches have exceeded TACs in numerous years, yet the stock has proved resilient and not collapsed like many in the northwest Atlantic (Figure 6.29).

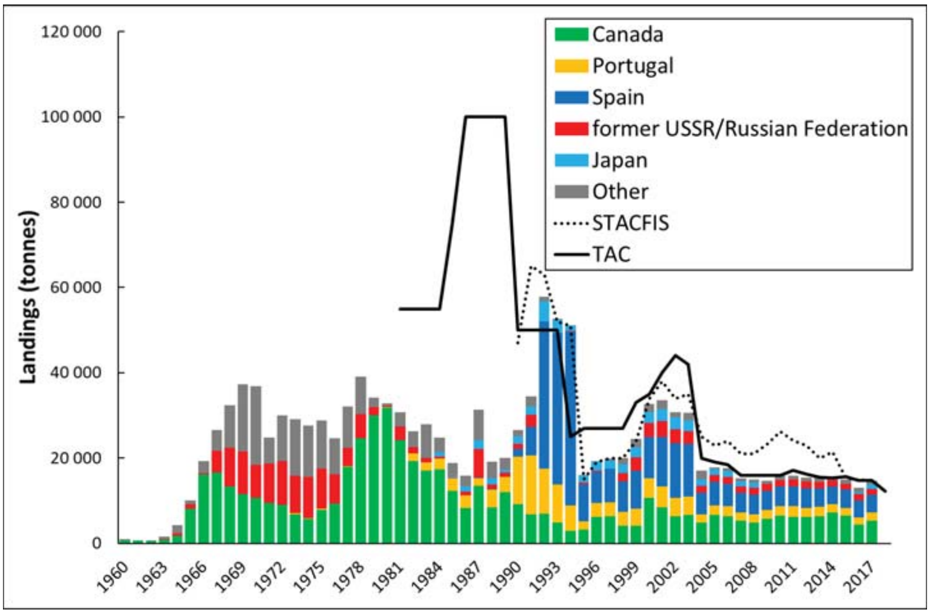
Canada's share of the catch which has been taken almost entirely within its own EEZ (at least in recent years), has risen from about one third to nearly half. Distant-water nations have fished in the NRA, with Spanish vessels taking about half of their combined catches, while Japan, Portugal and the Russian Federation have accounted for almost all of the remainder. Officially reported catches were relatively constant from 2005 to 2017, at around 15 000 tonnes per year, though NAFO Scientific Council estimates that catches have decreased from 23 000 tonnes to 14 800 tonnes during this period. The TAC, which since 2010 has been estimated from a harvest control rule and previous year's catch, has declined slightly over this period from 19 000 tonnes to 14 800 tonnes.

FIGURE 6.28
Greenland halibut bottom high seas trawl fishing effort in Division 3LMNO for 2015 showing areas of the main fishery and VMEs



The main Greenland halibut fishing grounds, in decreasing area of importance, are: (1) the northeast of Division 3L, (2) the northwest of Division 3M, (3) the southeast of Division 3L along the Division 3LM boundary, and (4) the northeast of Division 3N.
Information from daily catch reporting and vessel monitoring system position reporting.
Source: NAFO, 2016.

FIGURE 6.29
Landings of Greenland halibut from SA2 and 3KLMNO, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

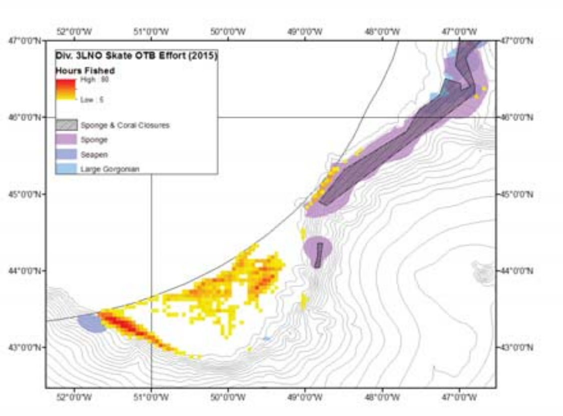
The current state of the stock is uncertain. The fishery has been fairly stable, in spite of poor recruitment since 2009, as measured by the abundance of age 4 fish in surveys. The surveys have provided conflicting results, though none cover the full area inhabited by the stock. The TAC for Greenland halibut in Division 3LMNO in 2016 was 10 966 tonnes. The high seas catch in 2016 was 8 499 tonnes.

Trawling for Greenland halibut in the northwest Atlantic is one of only three fisheries worldwide that has ever operated as deep as 2 000 m, though 1 500–1 700 m would be considered the more usual maximum depth for this fishery. The same could be said of the other two very deep fisheries: the former trawling for roundnose grenadier in the northwest Atlantic and toothfish longlining in the Southern Ocean.

Fishery for thorny skate

Skates of various species have no doubt been taken and discarded since the advent of fisheries in the northwest Atlantic. Reported landings of them from Grand Bank only began in the mid-twentieth century and they have since been dominated by thorny skate, which have comprised about 80 percent of the total, if not more. That species has a very wide depth range, from inshore waters to far down the continental slope, to depths of at least 1 400 m. Bycatches have been taken in the deep Greenland halibut fishery, among others, but directed trawling for thorny skate has apparently always been at continental-shelf depths of 100–500 m. On Grand Bank, the species is abundant from the Southeast Shoal westwards but less so further north, though its centre of distribution has changed over the decades (Figure 6.30; Kulka and Mowbray, 1999; Simpson *et al*., 2016). Thorny skate is taken to be a single stock of the Grand Bank, but is assessed separately in Division 3Ps (by Canada and France (St. Pierre et Miquelon), in their respective EEZs) and in Division 3LNO by NAFO. The catch from 3Ps only accounts for about 10 percent of the total and will not be discussed further. Skate are also caught around the Flemish Cap, but these are not assessed.

FIGURE 6.30
Skate bottom high seas trawl fishing effort for 2015 in Division 3LNO, and areas important for VMEs



Information from daily catch reporting and vessel monitoring system position reporting.
Source: NAFO, 2016.

Landings of skates caught in SA 3 were distinguished in published ICNAF statistics from 1954.[16] However, the reported landings from Division 3LMNO (of all skate species combined)[17] did not exceed 1 000 tonnes in any year before 1969 and increased slightly to 1 200–3 100 tonnes annually for 1974–1984 due to increased catches by the former USSR. A directed high seas skate fishery, primarily by Spanish trawlers, commenced in 1985 with fishing concentrated on the tail of the Bank, supported by fleets from Portugal and the former USSR/Russian Federation. Catches from Division 3LNO peaked in 1991 at 28 400 tonnes and again in 2000 at 18 300 tonnes, with catches in intervening periods dropping as low as 5 000 tonnes (Figure 6.31). Meanwhile, a short-lived fishery developed on Flemish Cap during the 1985–1995 period, involving the same three fleets, with catches rising rapidly to 5 000–7 000 tonnes, though catches fell from 1996 to less than 1 000 tonnes and less than 100 tonnes from 2013 (Figure 6.32).

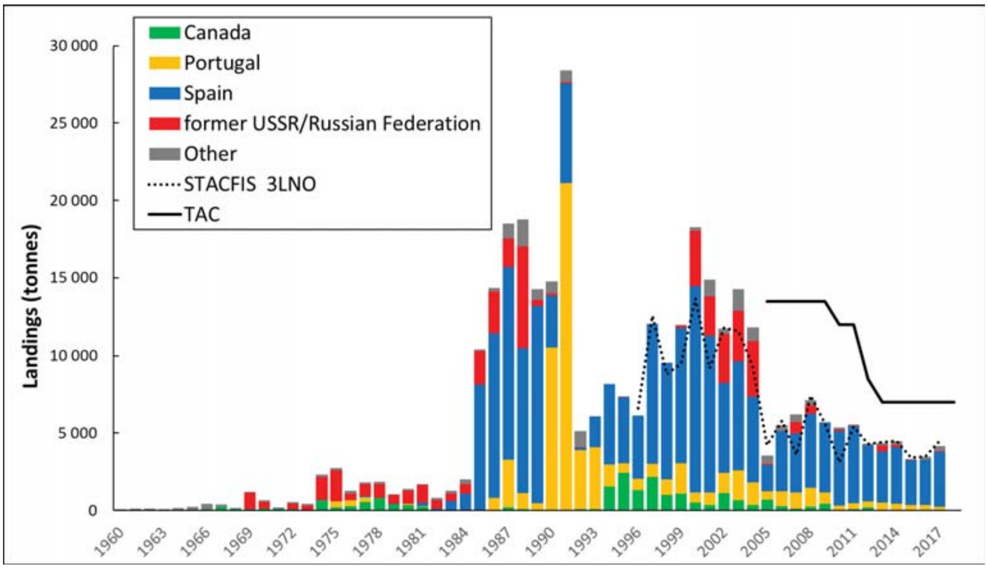
Exploited by bottom trawls, gillnets and longlines, the skates continue to support one of the larger bottom fisheries in the high seas of the region. Overall landings from Division 3LNO have declined steadily since the 2000 peak, and appear to have been relatively stable at around 4 000 tonnes per year since around 2012. Bycatches of skates are taken in various fisheries, including the deep trawling for Greenland halibut. However, the directed fishery appears to have been on the continental shelf, at less than 200 m depth (Iriondo *et al*., 2014). The high seas catch in 2016 is estimated at 3 481 tonnes.

The stock is considered to be at an intermediate level, as it is above the biomass limit reference point but still at a low level compared to recent historical biomasses. Recruitment has fluctuated around an average level, and the current fishing mortality is considered low. The life history characteristics of thorny Skate result in low rates of population growth and are thought to lead to low resilience to fishing mortality (NAFO, 2018a).

[16] Information from ICNAF *Statistical Bulletins* for 1951–60.

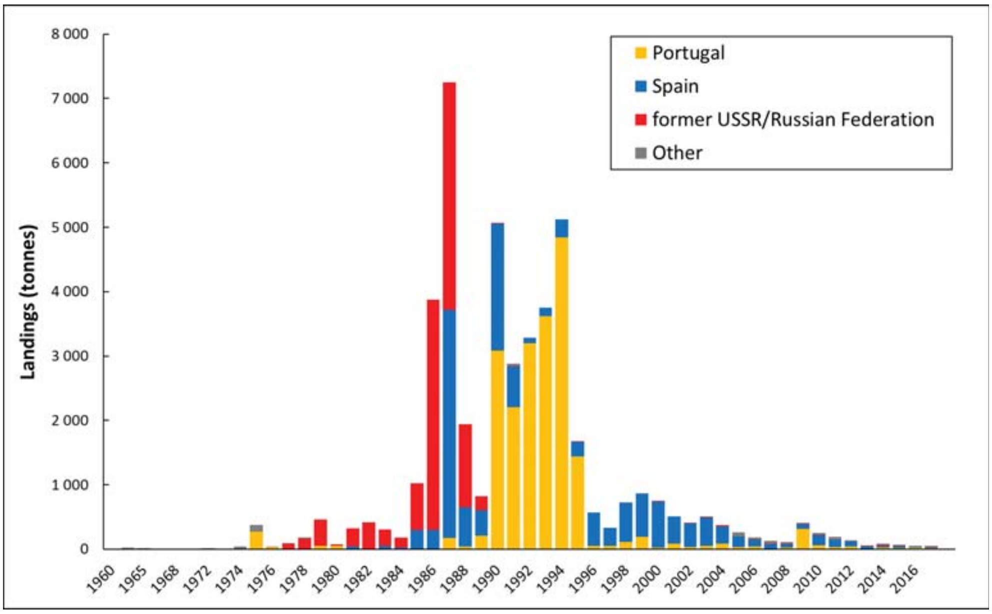
[17] The various species of skates did not begin to be separated in the NAFO STATLANT "21A" database before 2014. Nor have they usually been distinguished by processors when purchasing catches (Kulka and Mowbray, 1999).

FIGURE 6.31
Landings of skate in Division 3LNO since 1960, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

FIGURE 6.32
Landings of skate in Division 3M



Source: STATLANT 21A and NAFO SC reports, NAFO website.

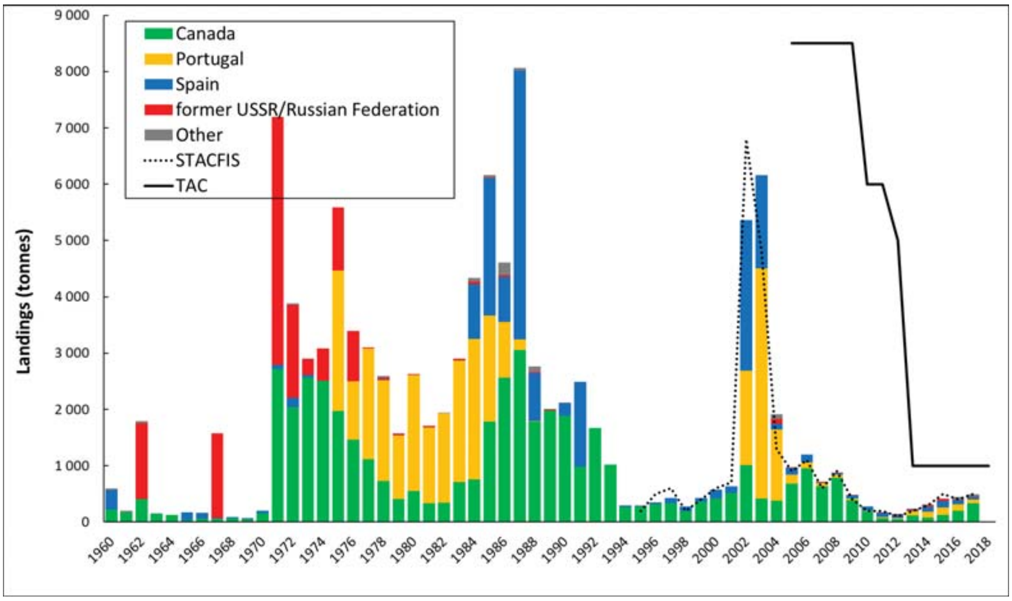
Fisheries for white hake

White hake have long been taken as bycatch, as a secondary target species or the primary target of some sets on trips otherwise aimed at other species – this pattern is evident in the deep longline fishery for Atlantic halibut, where some of the hake caught are utilized as bait but the hooks are sometimes targeted on that species (Kenchington and Halliday, 1994). Only twice, and then briefly, have there been substantial directed hake fisheries in SA 3. There, the resource is spread along the edge of the banks and across the upper continental slope from the tail of the Bank westwards. White hake do occur in exploitable quantities in the NRA but that is at the limit of their commercially viable distribution.

Landings of white hake have been recorded separately since 1960, but until 1970 combined landings from Division 3LMNO had only exceeded 1 000 tonnes in any one year on two occasions. In 1971, landings jumped to 7 200 tonnes, including 4 400 tonnes taken by the former USSR and 2 700 tonnes by Canadian vessels. Landings remained above 1 000 tonnes each year until 1993. For the first few years, Canadian vessels dominated the catch, but Portugal led the fishery from 1977 until 1985. Thereafter it became primarily a Canadian fishery again, and exclusively so when other fleets were shut out of the EEZ in 1992, with one exception: Spanish trawlers landed 4 800 tonnes of the 8 200 tonnes reported in 1987, during the period when the European Union set unilateral quotas. Canadian vessels landed 1 700 tonnes in 1992 but their directed fishery was closed, along with many others, the following year. Bycatches of hundreds of tonnes annually continued for the remainder of the decade (Simpson *et al*., 2015).[18] Most of those catches were very likely taken within what is now the Canadian EEZ but the 1987 Spanish fishery must have been conducted in the high seas (Figure 6.33).

The 1999 year-class of white hake proved to be exceptionally strong, contributing ten times the recruitment of year-old fish than any other year-class during the present survey series. A directed fishery emerged in 2002, largely under Portuguese and Spanish flags, which raised overall Division 3LMNO landings to 6 000 tonnes in 2002 and 6 500 tonnes the following year, before catches declined again. In 2009, landings were below 500 tonnes, suggestive of bycatches, and have been even lower ever since. NAFO imposed a TAC in 2004 but it was set at or above 5 000 tonnes, and hence above the catches, before being reduced to 1 000 tonnes for 2013 (Simpson *et al*., 2015). Catch reports from the high seas totalled 447 tonnes in 2016. Those were taken primarily

FIGURE 6.33
Landings of white hake in Division 3NO, STACFIS catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

[18] Simpson *et al.* (2015) considered the white hake in the Division 3NOPs management unit, using the NAFO STATLANT data for catches. The landings given here were drawn from the same database but for Division 3LMNO, thus including the same bycatches taken on the Nose of the Bank and on Flemish Cap that were considered by Simpson *et al.* (2015), while excluding the catches from St. Pierre Bank.

by vessels from Spain, Portugal and the Russian Federation, with some perhaps by Canadian vessels in 2016.

Bottom trawl fishery for northern shrimp

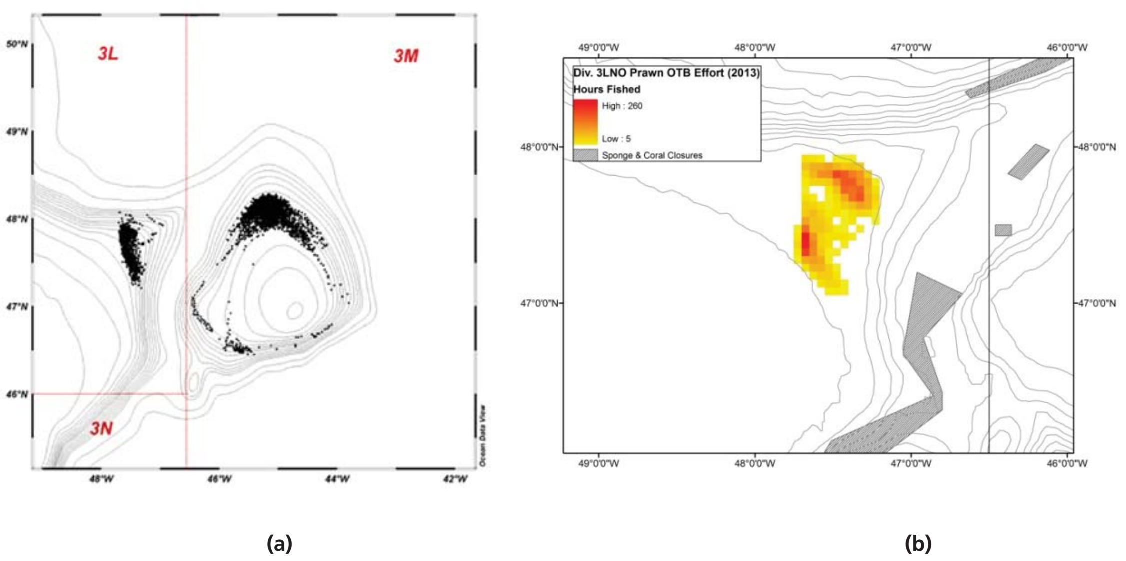
Region-wide northern shrimp landings from the northwest Atlantic rose slowly from the 1960s to over 50 000 tonnes in the mid-1970s, peaked at nearly 360 000 tonnes in 2004. Thereafter they declined quite quickly to 188 000 tonnes in 2016 (Lilly *et al.*, 2000; Rose, 2007; FAO, 2019a). The high seas fishery, though only recorded separately for recent years, has always been a minor portion of those regional totals.

The portion of the fishery in the high seas is managed as two stocks: Division 3M on the Flemish Cap and Division 3LNO that straddles the EEZ boundary (Figure 6.34a, b). While the second unit includes Division 3NO, almost all of the resource has been in Division 3L, at depths of 185–550 m, with the remaining biomass in Division 3N (Orr and Sullivan, 2014). In practice, most of the Division 3LNO fishing has been in waters under national jurisdiction but the grounds extend into the high seas area around the Nose of the Bank. The fishing in Division 3M was at 150–620 m depth and concentrated at around 400 m (Parsons *et al.*, 1998). The fishery only made use of otter trawls, with some of the larger vessels working two nets simultaneously. From 1994, all of the nets were required to be fitted with sorting grates to minimize finfish bycatches (Parsons *et al.*, 1998).

The 3LNO northern shrimp fishery was exploited by Faroese vessels from 1993, with catches approaching 2 000 tonnes in that and the following year, but falling sharply thereafter. Canadian vessels started to catch good numbers from 2000, likely mostly within their EEZ. Additional distant-water fleets joined the fishery from 2004. Catches increased rapidly to peak at 27 000 tonnes in 2009, but then started to decline rapidly. The last year showing any significant catches is 2014, the majority of which were taken by the Canadian fleet. However, by 2012 it had all but entirely withdrawn from the NRA, working only in its EEZ (Orr and Sullivan, 2014). The fishery was

FIGURE 6.34

Bottom trawl fishery for shrimp giving: (a) positions of vessels in Division 3L and Division 3M during October–December 2006 from VMS information, and (b) trawl fishing effort for 2013 in Division 3L (the Division 3M shrimp fishery was closed in 2011) and areas important for VMEs



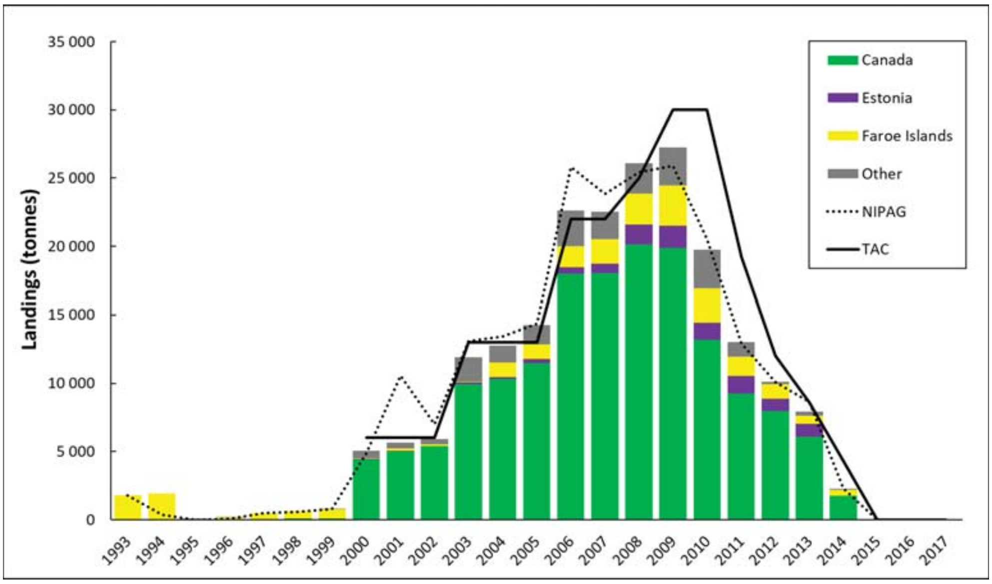
Source: Campanis and Thompson, 2007; NAFO, 2016.

closed in 2015. TAC limitations were introduced from 2000, which restricted catches during the growth phase but not in the decline phase, with the stock falling quicker than the TAC (Figure 6.35).

The 3M northern shrimp Flemish Cap fishery started rather suddenly in 1993, or at least the reporting of it did, when vessels from several distant-water nations including Estonia, Faroe Islands, Iceland, Norway, and others caught a total of 25 500 tonnes (Figure 6.36; Parsons *et al.*, 1998). The fishery expanded rapidly and catches peaked at

FIGURE 6.35

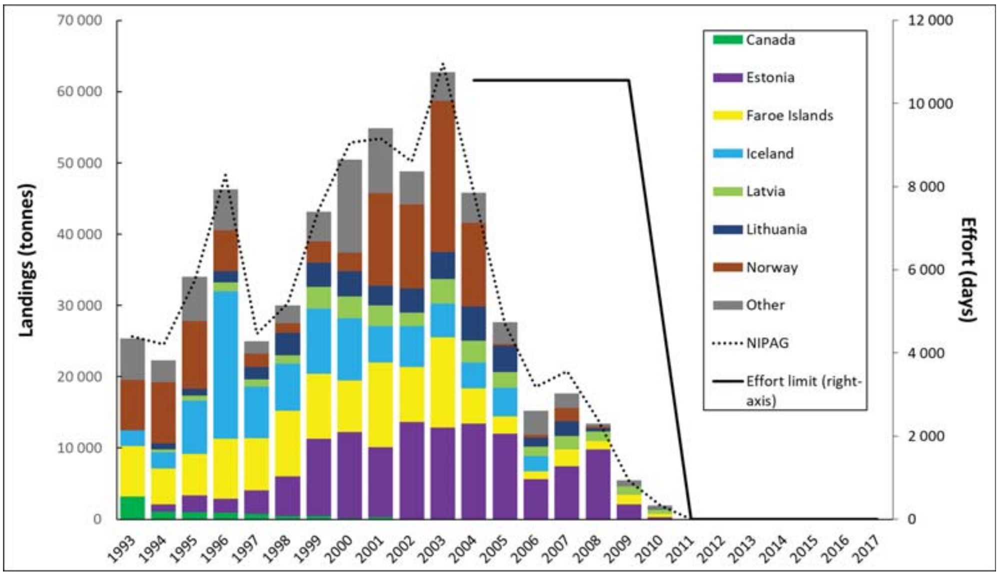
Landings of shrimp in Division 3LNO (EEZ and high seas) since 1993 and showing NIPAG catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

FIGURE 6.36

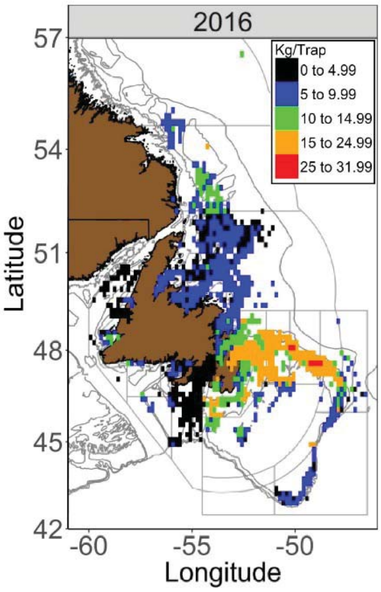
Landings of shrimp in Division 3M since 1993 and showing NIPAG catch estimate and TAC



Source: STATLANT 21A and NAFO SC reports, NAFO website.

64 000 tonnes in 2003. Catches declined rapidly thereafter and by 2010 the fishery had finished; it was formally closed in 2011. Effort restrictions were introduced in 2004, but did not halt the decline of the stock.

FIGURE 6.37
Spatial distribution of commercial snow crab fishing effort and CPUE during 2016



Divisions are Canadian management areas with outer line corresponding to the 200-nautical-mile limit. Depth contours are also shown.
Source: Fisheries and Oceans Canada, http://waves-vagues.dfo-mpo.gc.ca/Library/40712795.pdf

Canadian pot fishery for snow crab

Canadian fishermen harvest snow crab from the waters off southern Labrador to those off eastern Nova Scotia, as well as from the Gulf of St. Lawrence eastwards across the Grand Banks (Figure 6.37). There is one extensive fishery area on the northern side of Grand Bank, mainly in Canadian waters but extending into the "nose" in the high seas (Division 3L), and a second on the "tail" of the Grand Bank completely within the high seas (Division 3N). Snow crab is regarded as a sedentary species and the resource belongs to, is managed by and exploited by Canada, including in the high seas. Annual catches for the whole region are currently falling and overall biomass has declined to a historic low, particularly in the stocks in 3LNO, and more so outside of the 200 nautical-mile limit (DFO, 2018). It is suspected that colder conditions and a reduction in cod predation led to an increase in resource productivity in the 1990s that has reversed in recent years, and ecosystem conditions currently appear less favourable (Mullowney *et al*., 2016).

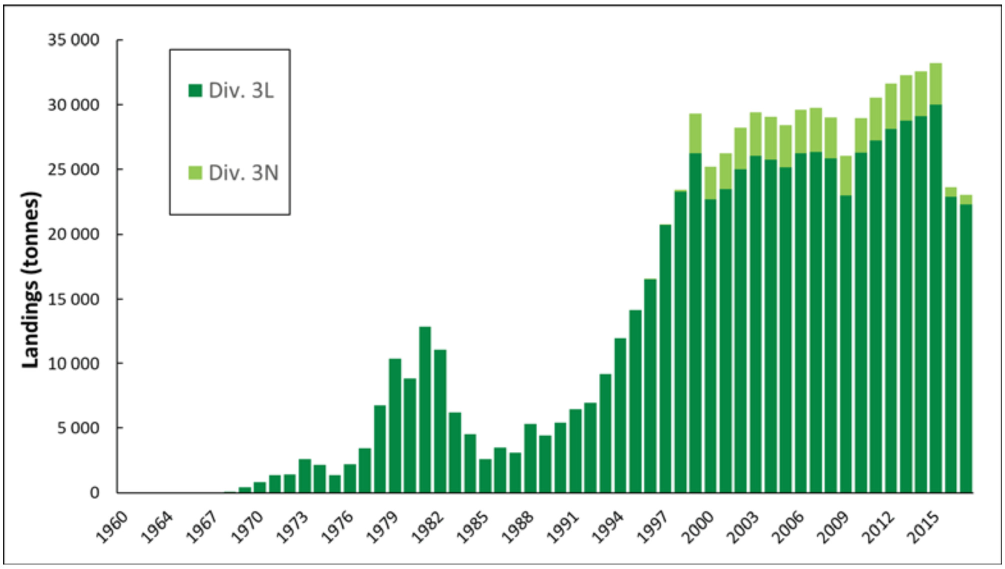
The 3LNO offshore stocks straddles the EEZ/high seas boundary and are managed as a single unit. Examination of Figure 6.37 shows that the high seas catch of the 3L fishery is relatively small. The 3L fishery started around 1970 and the catches show two distinct peaks: a smaller one around 1981, of almost 13 000 tonnes, and a much larger and broader peak from 1999 to 2015 reaching 35 000 tonnes (Figure 6.38). Catches on the tail of the Grand Bank are more modest, and have been relatively stable at around 3 000–3 500 tonnes from 1999 to 2015. However, snow crab abundance in both areas appears to have declined significantly in the last few years (DFO, 2018). There are no catches from the high seas part of Division 3O. Additionally, the crabbers rarely work Flemish Cap although 23 tonnes were taken there in 2008 and a further 8 tonnes over the next two years. Division 3M has not been fished since 2010.[19] In this case, the high seas catch is estimated as the catch in Division 3N only, amounting to 742 tonnes in 2016 (though this misses a small but unknown portion caught in high seas part of Division 3L); this represents a substantial decline from the 3 528 tonnes caught in 2014.

Canadian dredge fisheries for Iceland scallop and Arctic surfclam

After exploratory surveys, a Canadian commercial fishery for Iceland scallop began on Grand Bank in 1993, intended in part as a diversification of fishing effort, following closures and quota reductions in the groundfish sector during 1992–1993. The scallop dredging continued to the end of that decade but has been minimal since the turn of the century. The primary ground lay around the heads of Lilly and Carson canyons, on the eastern flank of the Bank, where the scallop beds straddle the EEZ boundary. Other exploited beds were along the shelf break, both to the northward and southward of

[19] Division 3M catch data from NAFO STATLANT 21A database.

FIGURE 6.38
Catch of snow crab in Division 3L (mostly within Canadian EEZ) and 3N (high seas only); all snow crab are caught by Canada



Source: STATLANT 21A and reports, NAFO website.

the canyons – and hence in the high seas. Catches there totalled a few thousand tonnes in 1996, the first year that those beds were actively fished, but declined thereafter (DFO 1997, 2009).

Hydraulic dredging for Arctic surfclam, using large factory vessels with onboard processing, commenced on Banquerau, well inside the Canadian EEZ, in 1986. The fishery spread to Grand Bank three years later and catches from the latter area peaked at nearly 20 000 tonnes (including the weight of the shells) in 1993, when Banquereau was not dredged at all. Thereafter, fishery-wide catches have been maintained at about 20 000 tonnes to 30 000 tonnes annually but, since 1995, most have come from Banquereau. The Grand Bank fishery ceased entirely after 2006, though quotas continue to be set and the one company active in the fishery could direct its vessels back into the area. The clams are widely spread across the eastern portion of the Bank. However, when that area was still actively fished, most of the effort was along the shelf break in Division 3N, straddling the EEZ boundary but largely in the high seas (DFO, 2010).

Both scallop and surfclam are deemed to be sedentary species and hence fall under Canadian jurisdiction its extended continental shelf.

Seamount fisheries

The former USSR sent an exploratory vessel to the Corner Rise Seamounts in 1976. She was followed by commercial trawlers and their combined catch that year exceeded 10 000 tonnes, which was composed mostly of splendid alfonsino caught primarily by midwater trawls, but with some bottom trawling.[20] However, only some 800 tonnes could be taken the following year and thereafter the seamounts were left to exploration and research vessels for the next ten years – even though annual catches could be as high as 530 tonnes. Commercial trawlers returned in 1987, taking 2 300 tonnes. In 1994, a single vessel took 400 tonnes; the following year as many as five took 3 500 tonnes

[20] The early catches taken in the Corner Rise area were not reported to ICNAF and do not appear in the NAFO catch database (Thompson and Campanis, 2007). The seamounts north of 35° N had been in ICNAF Statistical Area 6 since 1967 but that was not part of the ICNAF CA (Halliday and Pinhorn, 1990).

between them, but in 1996 the catch dropped again to 600 tonnes and the fishery seems to have been essentially abandoned thereafter. Throughout, alfonsino was the principal species taken but cardinalfish, black scabbardfish, wreckfish and others were landed. Alfonsino aggregations were mostly found at 420–750 m depth, while they and other species were taken as deep as 950 m (Vinnichenko, 1997; Vinnichenko and Kakora, 2008). As the depth ranges might suggest, much of the fishing, and all of the bottom trawling, was on Kükenthal Peak (referred to as *Perspektivnaya* in the Russian literature). However, there was some midwater trawling over *Vybornaya* (C-3 Seamount) and, immediately south of 35° N, over *Reservnaya* (Milne-Edwards Peak of Caloosahatchee Seamount: Vinnichenko, 2015).

Canadian vessels explored the Corner Rise Seamounts in 1995, using trawls, pots and longlines (Kulka *et al*., 2007), but no known fishery was developed. Some of the New England seamounts have seen exploratory fishing, including midwater trawling by the Spanish vessel which worked the Corner Rise Seamounts in 2004. However, no known high seas commercial fishing has developed on the peaks in the high seas (Kulka *et al*., 2007; Thompson and Campanis, 2007). A large closure to bottom fishing, intended to protect VME and spanning most of the seamount chain, has been in place since 2007.

Russian, French and Japanese vessels returned to the area early in the new century but with no greater results reported than had been achieved before (Clark *et al*., 2007). In 2004, a Spanish vessel fished with both midwater and bottom trawls. The former caught little, but bottom trawling on Kükenthal Peak was more successful. In all, the trawler took 415 tonnes of alfonsino and 21 tonnes of other species – mostly black scabbardfish and cardinalfish. Some lost pots were retrieved, suggesting past unreported fishing effort. There was further Spanish fishing the following year, taking 1 187 tonnes of alfonsino, but subsequent catches have remained under 500 tonnes annually (Thompson and Campanis, 2007; González-Costas, 2015; Vinnichenko, 2015). Bensch *et al.* (2009) noted a report of an Estonian trawler in the area in 2006 but it only took a few tonnes of catch. In order to protect VMEs, much of the Corner Rise area, including the summit of Kükenthal Peak, was closed to commercial bottom-contact fishing from 2007. Subsequent trawling should have been entirely midwater and hence outside the scope of this review.

Spanish trawlers fished Kükenthal Peak in the spring of 2010 and again in each year from 2012. Total reported alfonsino catch, viewed across 2010–2013, was 452 tonnes, while the bycatch totalled 6 tonnes. In 2014, the catch was 118 tonnes of alfonsino and 7 tonnes of other groundfish, while only 66 tonnes of alfonsino were taken in 2015. Observer reports have confirmed that only midwater sets were made, some over the summit of the Peak and others in deep water nearby (NAFO 2013, 2014, 2015, 2016; González-Costas, 2015). However, while some sets were made with a pelagic trawl of the "Gloria" type, most of the fishing used "Pedreira" gear (González-Costas, 2015), which is usually considered a bottom trawl – suggesting an expectation that seabed contact might occur. The use of such gear in the NAFO seamount closures was prohibited from 2016, which may have effectively ended the fishery.

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7. Central Atlantic Ocean

FAO Major Fishing Area 31, most of Area 34, plus a portion of Area 41

SUMMARY

The high seas of the Central Atlantic have only a few fishable features confined mainly to some seamounts in the Corner Rise group on the western side, and those of the Mid-Atlantic Ridge southwest of the Azores on the eastern side. Benthic productivity appears to be very low and most of the waters are too deep to support any demersal fisheries. There have been sporadic catches on the eastern side – mainly of alfonsino – amounting to nearly 100 tonnes in 2002, but typically catches are much lower than this, with often less than 10 tonnes reported per year. The have been no reported catches for the western side in recent years, though the southern part of the Corner Rise seamounts likely yielded catches in the past. No significant catch of deep-sea species was recorded in 2016.

GEOGRAPHIC DESCRIPTION

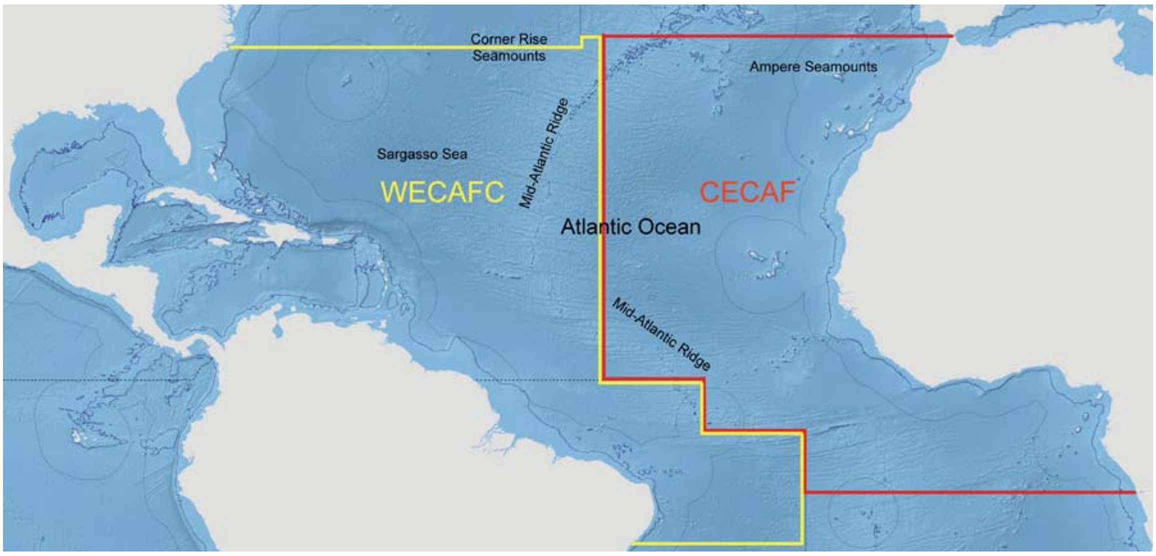
For the purposes of this review, the tropical and subtropical portions of the north and south Atlantic Oceans are considered to form the central Atlantic region (Figure 7.1). The marginal seas within those limits are included, except the Mediterranean Sea. More than half of the region falls within the high seas, though the EEZs around the island chains from the Bahamas to the Windward Islands form a continuous band. Almost all of the sea area further west falls under national jurisdictions, apart from two small enclaves in the Gulf of Mexico where the seabed is too deep for bottom fishing. The region's high seas form a contiguous area of open ocean, albeit one interrupted by EEZs around several island groups: Madeira (Portugal), the Canary Islands (Spain), Cabo Verde, São Tomé and Príncipe, Annobón (Equatorial Guinea), St. Peter and St. Paul Rocks (Brazil), Fernando de Noronha (Brazil) and Bermuda. The Azores (Portugal) lie outside the Central Atlantic to the north but the surrounding EEZ extends into the region.

The high seas of the region are predominantly deep ocean, though traversed by the Mid-Atlantic Ridge and dotted with seamounts. Only 61 000 km^2 are mapped as shallower than 2 000 m, of which just 3 000 km^2 is less than 400 m deep (Table 7.1). Among the seamounts, only the Corner Rise group (which straddles the boundary of the northwest Atlantic), Ampere Seamount (in the extreme northeast of the Central Atlantic) and a few seamounts on the Mid-Atlantic Ridge outside the EEZ around the Azores are notable for bottom fishing. There is also a group of seamounts extending southwest from the Guinea Terrace, in addition to another extending southwest from the Gulf of Guinea, though the extent of fishing on these is unknown.

TABLE 7.1
Area statistics for the central Atlantic Ocean

Geographical area	Surface area (km^2)
Total sea area	31 563 000
Area of high seas	17 752 000
Area of high seas shallower than 200 m	526
Area of high seas shallower than 400 m	3 000
Area of high seas shallower than 1 000 m	10 000
Area of high seas shallower than 2 000 m	61 000

FIGURE 7.1
Map of the central Atlantic Ocean showing the WECAFC area of competence (yellow line) and the CECAF area of the committee (red line)



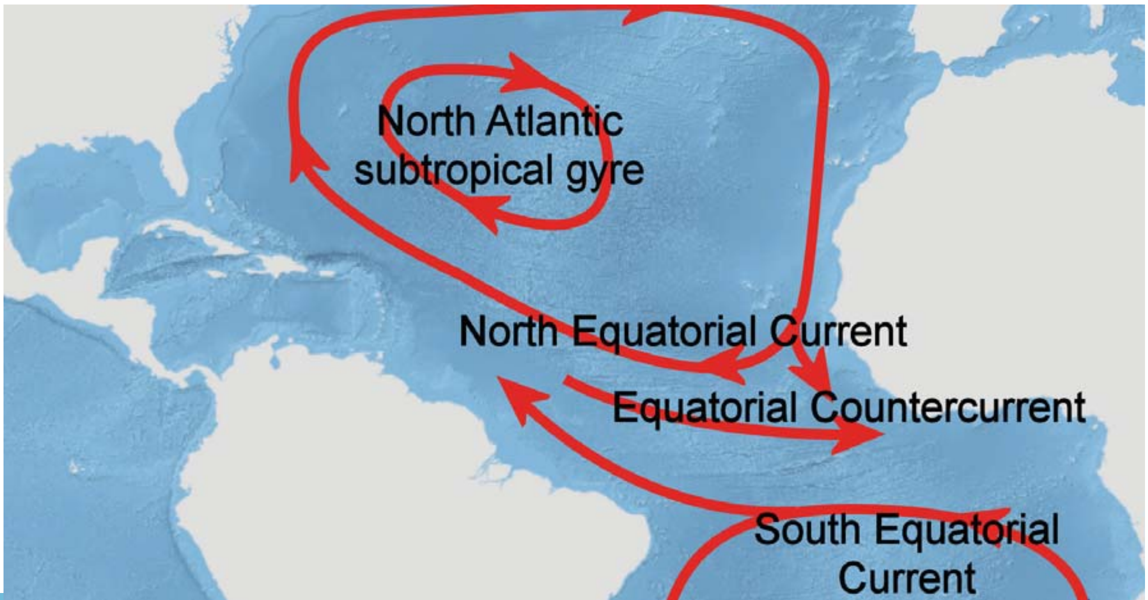
200 nautical mile arcs, 2 000 m isobath (GEBCO), FAO fishing areas.

Source: FAO VME Database, Mercator projection.

ECOSYSTEMS AND RESOURCE SPECIES

The oceanography of the region is dominated by the westward-flowing North and South Equatorial Currents, and by the North Atlantic subtropical gyre (Figure 7.2). The latter, much like its analogues in the Pacific and Indian oceans, has not proven to be particularly productive for deep-living fishery resources: most of what is available is found in the warm–temperate, northernmost part of the region, rather than the tropical and equatorial belts further south.

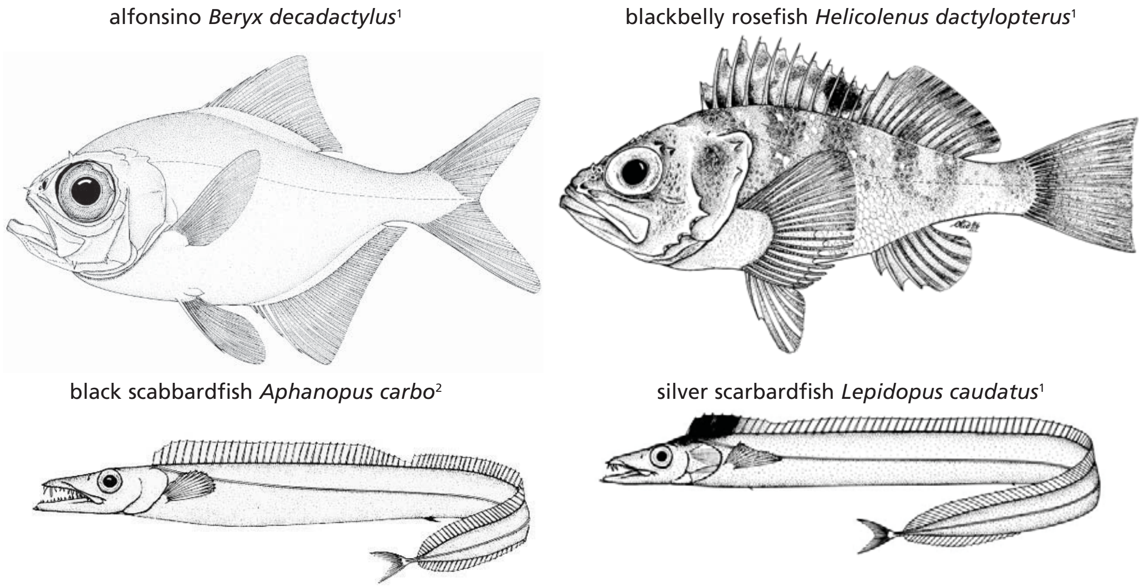
FIGURE 7.2
Dominant ocean currents in the central Atlantic Ocean



Source: FAO VME Database, currents added.

A variety of resource species are available for small-boat fisheries around islands, including on a few of the high sea seamounts near the Azores. However, the only species offering catch rates sufficient to support large vessels working far from land are alfonsino, silver scabbardfish and black scabbardfish, particularly from the Mid-Atlantic Ridge eastwards (Figure 7.3). Alfonsino have been harvested across the region's temperate latitudes but predominate in catches from the seamounts in the northwest.

FIGURE 7.3
Principal demersal resource species of the high seas of the central Atlantic



Source:
[1] Food and Agriculture Organization of the United Nations, Original Scientific Illustrations Archive.
[2] www.fao.org/fishery/species/2469/en

MANAGEMENT OF HIGH SEAS BOTTOM FISHERIES

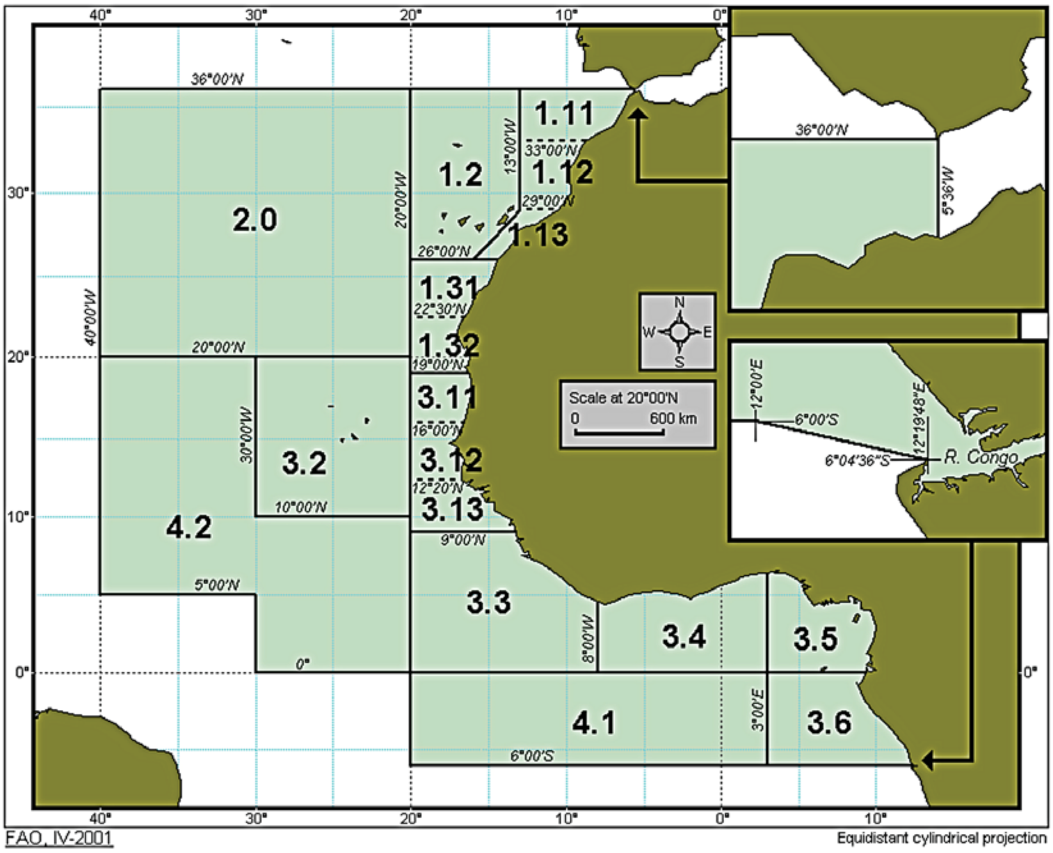
At present there is no regional management body with competence over high seas bottom fisheries in the Central Atlantic. There are, however, two regional fisheries bodies: the Fishery Committee for the Eastern Central Atlantic (CECAF) and the Western Central Atlantic Fishery Commission (WECAFC). The former's area of competence encompasses all of FAO Major Fishing Area 34, while WECAFC oversees Area 31 and those parts of Area 41 that fall within the region.

Fishery Committee for the Eastern Central Atlantic (CECAF)

The Fishery Committee for the Eastern Central Atlantic (CECAF) was established by the FAO Council in 1967 as an FAO Article VI regional fisheries body.[1] It is advisory in nature and adopts non-binding recommendations. The committee has a broad role within its stated purpose of promoting the sustainable use of living marine resources through management and fisheries development. All living marine resources are included within its area of competence, which includes both the high seas and national jurisdictions. CECAF currently has 34 member states, including 20 coastal states, 13 other states, and the European Union. The area has been divided into divisions and subdivisions for the purposes of reporting fisheries catch (Figure 7.4).

[1] http://www.fao.org/fishery/rfb/cecaf/en

FIGURE 7.4
Divisions and Subdivisions of the CECAF area of competence



Source: http://www.fao.org/fishery/area/Area34/en

The Committee established a scientific subcommittee in 1998, which in turn established a permanent working group on demersal fisheries. However, to date, CECAF attention to such fisheries has been confined to support for, and the coordination of, work on resources and fisheries under national jurisdictions.

Western Central Atlantic Fishery Commission (WECAFC)

The Western Central Atlantic Fishery Commission (WECAFC) is also an advisory FAO Article VI regional fisheries body, established by the FAO Council in 1973.[2] While the formal wording of its objectives and principles differ from those adopted by CECAF, WECAFC has a similarly broad role within the objective of promoting the conservation, management and development of living marine resources. All living marine resources are included within its areas of competence, which again includes both the high seas and national jurisdictions. The commission currently has 34 members, including 30 coastal states, three distant-water fishing states, and the European Union. The Secretariat is provided by the FAO sub-regional Office for the Caribbean. WECAFC has a five-member Scientific Advisory Group, which meets biennially. Since 2014, there has been consideration of transitioning WECAFC from an FAO Article VI advisory body to an FAO Article XIV RFMO (WECAFC, 2014).

Much WECAFC work is undertaken by working groups established by the commission who provide specific terms of reference. Many of the groups are jointly

[2] http://www.fao.org/fishery/rfb/wecafc/en

organized with other regional bodies. The WECAFC Working Group on the Management of Deep-Sea Fisheries was established in 2012 by the commission alone. Its terms of reference concerned the collection and review of data and information, in addition to making recommendations to the commission. The working group hosted a *Technical Workshop on Bottom Fisheries in the High Seas Areas of the Western Central Atlantic* in 2014 (WECAFC, 2015).

DESCRIPTION OF HIGH SEAS BOTTOM FISHERIES

1839–1999

The Central Atlantic region saw early development of deep bottom fisheries, with line fishing for black scabbardfish, which began off Madeira in 1839 (Leite, 1989; Martins and Ferreira, 1995), and trawling for European hake off Morocco shortly after 1900 (Alward, 1932; Hickling, 1935). Deep fishing in the western central Atlantic has been a much more recent development. Those fisheries, however, were and are confined to waters now under national jurisdiction. High seas bottom fisheries have been limited to some distant "artisanal" fishing around archipelagoes (primarily the Azores) that extended more than 200 nautical miles from land and to seamount fishing by distant-water fleets. As expected for a low-latitude region, the latter's activity has been limited.

Trawlers from the former USSR fished seamounts around Madeira and the Canary Islands from 1970, primarily using midwater trawls to take pelagic species, though there was some bottom trawling and some targeting of silver scabbardfish. Most of the fished locations are now in EEZs, leaving only Ampere and Josephine seamounts in the high seas – the latter immediately outside the boundary of the Central Atlantic region. Total catches from the two have generally been less than 1 000 tonnes per year, much of which was comprised of pelagic species. That fishery ceased during the 1980s but resumed at a low level in the following decade (Clark *et al*., 2007; Vinnichenko and Kakora, 2008). The fleets of the former USSR also fished seamounts on the Mid-Atlantic Ridge south of the Azores from 1973, taking black scabbardfish at first, and alfonsino (along with pelagic species) from 1976. The total catch of these two demersal species over five years was 10 000 tonnes and 4 000 tonnes respectively. After 1977, some of the fished seamounts were within the EEZ around the islands, but the fishery continued outside on an occasional basis (Clark *et al*., 2007; Vinnichenko and Kakora, 2008).

The former USSR extended its seamount fishing to the Corner Rise Seamounts from 1976. The overall catch that year exceeded 10 000 tonnes, mostly composed of alfonsino that were primarily caught by midwater trawls, though there was some bottom trawling. Only some 800 tonnes could be taken the following year and the seamounts were left to exploration and research vessels for the next ten years, though annual catches could be as high as 530 tonnes. Commercial trawlers returned in 1987, taking 2 300 tonnes. In 1994, a single vessel took 400 tonnes; the following year as many as five vessels took 3 500 tonnes between them, but in 1996 the catch dropped again to 600 tonnes and the fishery seems to have been essentially abandoned since. Throughout, alfonsino was the principal species taken but cardinalfish, black scabbardfish, wreckfish and others were landed. Alfonsino aggregations were mostly found at 420–750 m depth, while they and other species were taken as deep as 950 m (Vinnichenko, 1997; Vinnichenko and Kakora, 2008). Much of the fishing was on the feature alternatively known as *Perspektivnaya* or the Kükenthal Peak of Corner Rise Seamount, though *Vybornaya* (C-3 Seamount) and *Reservnaya* (Milne-Edwards Peak of Caloosahatchee Seamount) were also fished. The first two lie north of 35° N and hence in the northwest Atlantic region. Bottom trawls were only deployed on Kükenthal Peak (Vinnichenko, 2015). Thus, catches from the Central Atlantic portion of the Corner Rise area were small and perhaps all taken without bottom contact.

2000 onwards

It is challenging to separate the catches in the high seas from those within national waters. Distant-water vessels from China, the Republic of Korea, and the Russian Federation have reported catching alfonsino and scabbardfish from most of the purely coastal subdivisions between Sahara coastal (Subdivision 1.3) to the southern Gulf of Guinea (Subdivision 3.6), owing to agreements with coastal states. Nevertheless, since the turn of the century, the central Atlantic high seas bottom fisheries have continued at around the same sporadic, low level they reached in the 1990s. Available sources do not permit a comprehensive, clear separation of information on such fisheries from those using off-bottom gear or those operating in national waters. There is some finer scale reporting to CECAF at the subdivision level, but in all cases the high seas oceanic areas include a small amount of EEZ waters (Figure 7.4). Furthermore, catches of typical deepwater demersal species have been reported by non-coastal states. Catches have been reported from the northern oceanic (Subdivision 2.0), southwestern oceanic (Subdivision 4.2), and southwestern Gulf of Guinea (Subdivision 4.1), but the latter two areas reported only alfonsino in 2005 at 46 tonnes, trivial catches (less than 2 tonnes) in 2002 and 2016, and no other reported catches of any demersal species. Catches of alfonsino, blackbelly rosefish and scabbardfish in the northern oceanic area have been reported by Spain, Portugal and the Russian Federation either in the Azores EEZ portion or the extension of the Mid-Atlantic Ridge to the southwest (Table 7.2). Catches have been sporadic and dominated by alfonsino, with over 10 tonnes per year in only six years of the 2000–2016 period. Minor catches of blackbelly rosefish have been reported, along with a single recent catch of 201 tonnes and 215 tonnes of black scabbardfish in 2016 and 2017 respectively, by Portugal (FAO, 2019). It is likely that much, if not all, of the above catch was taken by midwater trawling.

In the early twenty-first century Russian, French and Japanese vessels worked in the Corner Rise area but took little catch (Clark *et al*., 2007). In 2004, a Spanish vessel fished with both midwater and bottom trawls, the latter confined to Kükenthal Peak, and hence in the northwest Atlantic region. There was further fishing in subsequent years, with a maximum catch of 1 200 tonnes taken in 2005, but little (if any) of the fishing effort took place south of the regional boundary, and that apparently made exclusive use of midwater trawls (Kulka *et al*., 2007; Thompson and Campanis, 2007; Vinnichenko, 2015).

There has been no known high seas bottom fishing in the region by any of the coastal states in the Americas (WECAFC, 2015). No equivalent information is available from the eastern Central Atlantic, though it may be supposed that Azorean fishermen still sometimes fish more than 200 nautical miles from their islands.

Catches of deep-sea species taken by bottom-contact gear for 2016 from the Central Atlantic high seas appear to be very small. The catches given above, mainly alfonsino and scabbardfish, were likely taken mainly with deep midwater trawls, gears and longlines for the latter species. The only recorded catch in 2014 was 8 tonnes of blackbelly rosefish, probably caught incidentally along with other “pelagic” species.

TABLE 7.2
Catches (tonnes) of typical deep-sea demersal species for 2000–2016 from the high seas in the eastern central Atlantic (Subdivisions 2.0, 4.1 and 4.2)

Species	Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Alfonsino	Portugal								36	60		28						
	Russian Federation					69												
	Spain			93	18				2									
Blackbelly rosefish	Portugal								11	1				6	2	6		
	Spain								6						1	2		
Silver scabbardfish	Portugal											1						
Black scabbardfish	Portugal															1		201

Blank cells indicate no reported catches.
Source: FAO, 2019.

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8. Southeast Atlantic Ocean

FAO Major Fishing Area 47 and a portion of Area 34

SUMMARY

Despite the high productivity of the Benguela Current ecosystem in waters under national jurisdiction, the high seas of the southeast Atlantic provide few resources for bottom fisheries. There were brief opportunities for exploitation of virgin resources of alfonsino, pelagic armourhead and orange roughy, mainly in the 1990s. The last targeted orange roughy catches were recorded in 2005, and catches of alfonsino and pelagic armourhead in 2013. Occasional catches still occur when there is interest, but catches are sporadic, and rarely last for more than a year or so. Deep midwater trawls are also used to fish alfonsino and pelagic armourhead, and they are fished close to the sea floor. The Patagonian toothfish longline fishery and the red crab pot fishery started in the early 2000s and continues to date. The combined catches for the high seas bottom fisheries have been dropping in recent years, going from 188 tonnes in 2014 to only 60 tonnes in 2016 (Table 8.1).

TABLE 8.1
High seas bottom fisheries catch in the southeast Atlantic for 2014 and 2016

Gears	Principal grounds	Recent fishing history	Target species	2014 catch (tonnes)	2016 catch (tonnes)	Principal bycatch species
Bottom and midwater trawls	Valdivia Bank	-	alfonsino and pelagic armourhead	N/F	N/F	rosefish, cape bonnetmouth, imperial blackfish, oilfish, silver scabbardfish
Bottom trawls	Valdivia Bank and Ewing seamount	Zero TAC	orange roughy	N/F	N/F	alfonsino, pelagic armourhead, black cardinal fish, oreo dories, deep-sea shark
Longlines and trotlines	Discovery and Meteor seamounts	Japan 2003–2017 Spain 2002–2010 Republic of Korea 2003–2009 South Africa 2011–2012	Patagonian toothfish	79	60	grenadiers, antimora
Pots	Valdivia Bank	Japan 2005–2010 Namibia 2005–2017 Portugal 2007	red crab	135	N/F	none

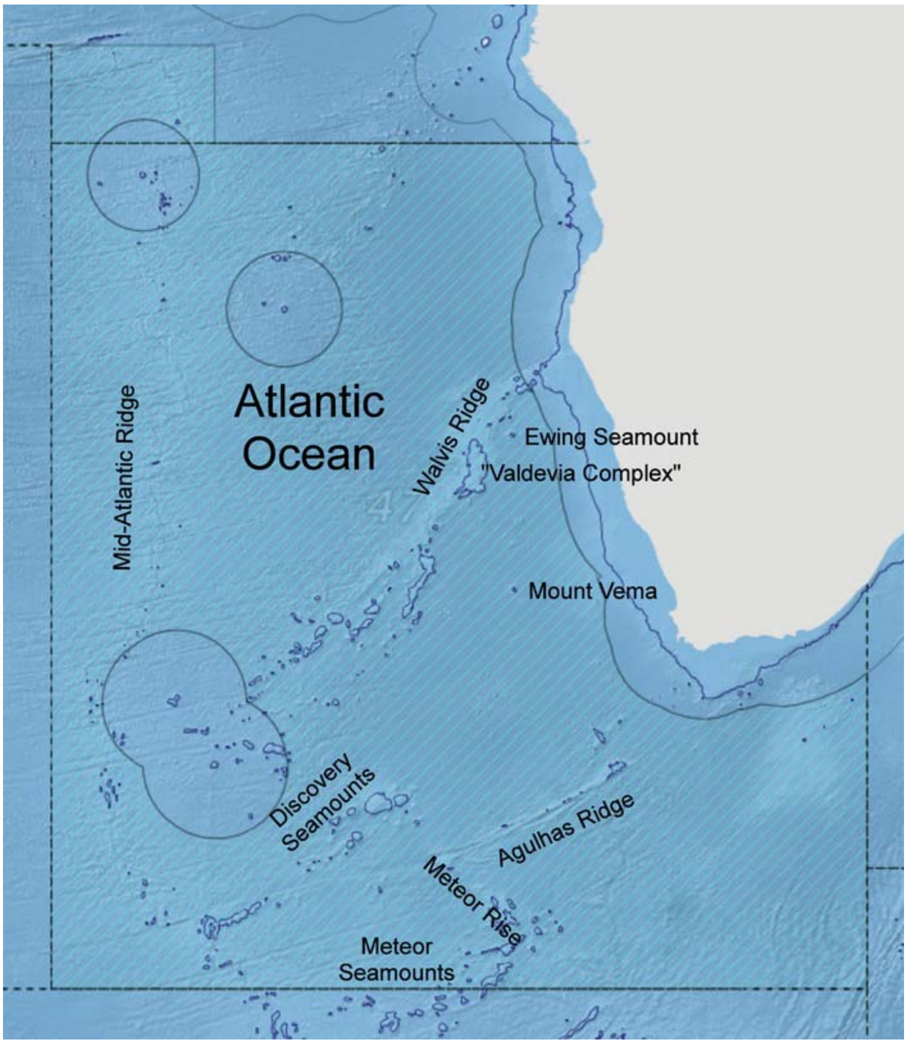
N/F – no fishing
Source: SEAFO, 2019.

GEOGRAPHIC DESCRIPTION

The southeast Atlantic region extends from the equator (between 20° W and 10° W) or the 6° S parallel (east of 10° W) to the Southern Ocean at 50° S, and from the mid-Atlantic at 20° W, into the Indian Ocean at 30° E, though its eastern boundary is mostly defined by the coastlines of Angola, Namibia and South Africa (Figure 8.1). There are also several offshore island territories in the southeast Atlantic, each with their own EEZs.

The African continental shelf is generally narrow and does not extend into the high seas of the southeast Atlantic at any point. However, the Mid-Atlantic Ridge (MAR) runs through the western portion of the region, at about 15° W, while a series of lesser ridges and

FIGURE 8.1
Map of southeast Atlantic Ocean showing the SEAFO convention area (shaded)



200 nautical mile arcs, 2 000 m isobath (GEBCO), FAO fishing areas.

Source: FAO VME Database, Mercator projection.

seamount chains run generally northeastwards, between geological "hot spots" near the main mid-ocean ridge and the continental margin. Most prominently, the Walvis Ridge and "Valdivia Complex" extend northeast from Tristan da Cunha to the northern Namibian continental slope. There are also isolated seamounts which rise to fishable depths, notably Mount Vema, the Discovery seamounts and the Meteor seamounts; in the south, the Meteor Rise and Agulhas Ridge provide further fishing grounds.

In the north, two points on the ridge systems rise above the sea surface: the islands of Saint Helena and Ascension. In the south, there are six islands in the Tristan da Cunha group. Together, these islands form the British Overseas Territory of Saint Helena, Ascension and Tristan da Cunha.

While the region's high seas include a moderate extent of potentially fishable seabed shallower than 2 000 m, little of it is shallower than 1 000 m (Table 8.2) and only five small areas are known to reach within 600 m of the surface (SEAFO, 2017b). Indeed, new mapping by RV *Dr Fridtjof Nansen* in 2015 found that a number of seamounts in the region are smaller and lie deeper than had been supposed, based on previously available GEBCO data (Anon, 2015). Thus, the area at fishable depths is probably smaller than is suggested in the data presented here, which is derived from GEBCO information.

TABLE 8.2
Area statistics for the southeast Atlantic

Geographical area	Surface area (km²)
Total sea area	19 079 000
Area of high seas	15 627 000
Area of high seas shallower than 200 m	3 000
Area of high seas shallower than 400 m	5 000
Area of high seas shallower than 1 000 m	30 000
Area of high seas shallower than 2 000 m	174 000

ECOSYSTEM AND RESOURCE SPECIES

The principal oceanographic feature of the southeast Atlantic is the highly productive Benguela Current, which flows northward along the African coast from the Cape of Good Hope to around 15° S–17° S at the Angola–Namibia border, where it meets the warm south-flowing Guinea and Angola Currents. These currents all turn westwards forming the South Equatorial Current, which is in turn part of the anti-clockwise South Atlantic gyre. The southern boundary of the southeast Atlantic is dominated by the Southern Ocean Current and is influenced by the Antarctic Convergence Zone. The deeper currents are affected by the topography of the various deep ocean ridges, and this tends to confine waters to the abyssal basins. Bottom water coming from the Weddell Sea in the Antarctic is unable to pass into the southeast Atlantic directly, as a result of the Agulhas and Walvis Ridge systems, but it flows along the South Atlantic's western boundary to fill the southeast Atlantic basins though deep passages in the MAR.

The upwelling water off Angola and Namibia is rich in plankton and can extend hundreds of kilometres from land but a consistent supply of prey – needed to sustain resources of long-lived demersal species – is confined within the EEZs of the coastal states. There, it supports rich fisheries, particularly for Merluccid shallow-water Cape, deepwater Cape hakes and pelagic species (Payne and Punt, 1995; Gordoa *et al.*, 1995; Durholtz *et al.*, 2015; Wilhelm *et al.*, 2015). While the hakes do not extend into the high seas, the fisheries for them provided a foundation for fleets to explore the ridges and seamounts further away from the coast.

Further offshore and into the high seas, the small areas at potentially fishable depths lie under oligotrophic waters. While there are viable epipelagic fisheries for tunas, such ecosystems are unproductive and there are only minor deepwater demersal resources. Small amounts of alfonsino, pelagic armourhead, orange roughy and red crab are harvested on various ridges and seamounts (Figure 8.2). Patagonian toothfish are found in the far south of the region and support a small yet developing fishery.

MANAGEMENT OF HIGH SEAS BOTTOM FISHERY

South East Atlantic Fisheries Organisation (SEAFO)

The multilateral management of the southeast Atlantic fisheries began with the International Commission for the Conservation of the Living Resources of the Southeast Atlantic (ICSEAF),[1] founded in 1971, which covered all fisheries within both the current day EEZs and high seas areas of the southeast Atlantic. However, implementation and enforcement of management measures became difficult due to non-compliance. South Africa declared a 200 nautical mile EEZ in 1977, at much the same time as many other coastal states. However, it delayed declaring an EEZ off the coast of Namibia (then under South African administration) until 1981. South Africa's jurisdictional claim was then disputed by distant-water fishing nations, and the rich continental-shelf grounds remained, de facto, a part of the high seas until Namibian

[1] http://www.fao.org/fileadmin/user_upload/legal/docs/015t-e.pdf

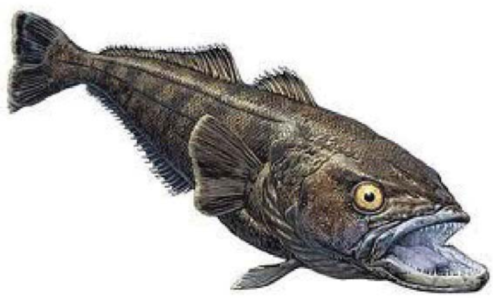
FIGURE 8.2
Principal demersal resource species of the high seas of the southeast Atlantic

deep-sea red crab *Chaceon erytheiae*

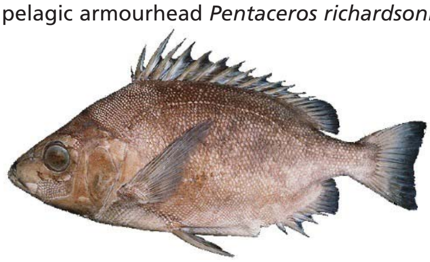
splendid alfonsino *Beryx splendens*

orange roughy *Hoplostethus atlanticus*

Patagonian toothfish *Dissostichus eleginoides*



pelagic armourhead *Pentaceros richardsoni*



Source: SEAFO, 2017a–e.

independence in 1990. The resulting international fisheries drew the commission's focus. Following Namibia's establishment of its own EEZ, the Commission largely lost its purpose and was terminated in 1990 (Miller, 2005).[2]

Negotiation of a convention for an RFMO to manage the bottom fisheries in the high seas of the southeast Atlantic region began in 1997, and lead to the formation of the South East Atlantic Fisheries Organisation (SEAFO) which entered into force in 2003.[3] SEAFO was the first RFMO to be established after the UN Fish Stocks Agreement entered into force, and this is reflected in its Convention (Miller, 2005). Its stated objective is:

> *to ensure the long-term conservation and sustainable use of the fishery resources in the Convention Area (Article 2), [and a commitment] to safeguarding the environment and marine ecosystems in which the resources occur (Article 3).*

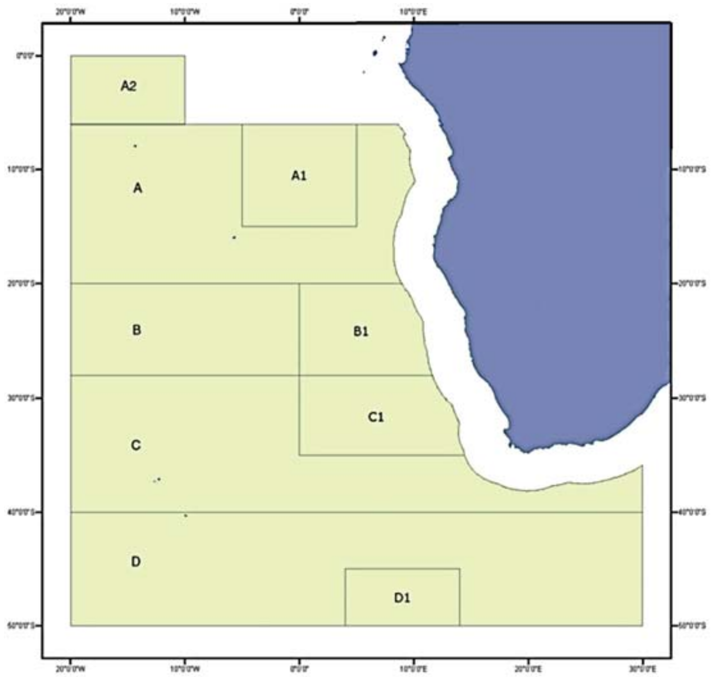
Those aims are advanced based on scientific advice, through the application of both the ecosystem approach to fisheries management and the precautionary approach.

2 http://www.fao.org/fileadmin/user_upload/legal/docs/madrid2-e.pdf
3 http://www.seafo.org/About/Convention-Text

There are currently seven contracting parties, comprising the three mainland coastal states, three distant-water flag states and the EU.

The SEAFO convention area corresponds to the high seas portion of FAO Major Fishing Area 47, but also includes those parts of a rectangle (within FAO Major Fishing Area 34) bounded by the equator, the 6° S parallel and the meridians of 10° W and 20° W, which fall within the high seas. Said rectangle also falls within the area of competence of the Fishery Committee for the Eastern Central Atlantic (CECAF). The area is divided latitudinally into four Subareas (A–D), each of which contains a division (A1, B1, C1 and D1) where the majority of the high seas bottom fishing has occurred (Figure 8.3).

FIGURE 8.3
Map showing SEAFO convention area and statistical divisions



Source: Southeast Atlantic major fishing area 47, http://www.fao.org/fishery/area/Area47/en

Decisions relating to fisheries management are undertaken by the SEAFO Commission, which adopts measures based on advice from the scientific and compliance committees to control the impacts of fishing on stocks and the ecosystem (Table 8.3). From 2014 onwards, SEAFO integrated many of the Conservation Measures (CM) into a new and comprehensive System of Observation, Inspection, Compliance and Enforcement,[4] which includes mechanisms for managing the fisheries. The system requires contracting parties to submit details of all vessels authorized to fish in the SEAFO convention area and to take action under their domestic laws to prevent fishing in the convention area by other vessels; it prohibits trans-shipping within the convention area, requires that vessels make every reasonable effort to recover lost gear and notify their flag state of lost and/or retrieved gear, as well as setting requirements for the labelling of frozen fishery products. Under the *SEAFO System* vessels are required to maintain logbooks (including geo-referenced set-by-set records of catches, discards, gear and fishing times), as well as records of retained catch and its stowage. Each vessel must be equipped with vessel monitoring system (VMS) equipment that transmits automatically at least every two

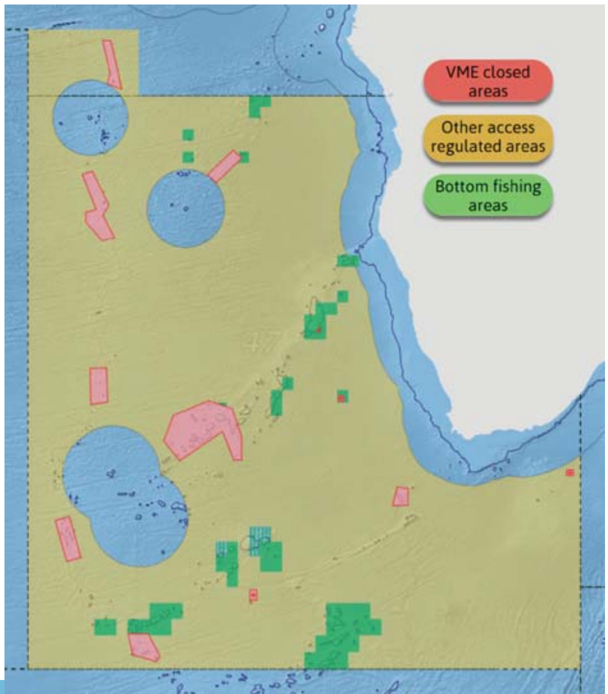
[4] http://www.neafc.org/managing_fisheries/measures

hours, sending the vessel's position, course and speed data to its flag state. All vessels operating in the convention area are required to carry observers qualified by the flag state. There are standard reporting requirements for at-sea inspections. Furthermore, the system outlines designated ports, with foreign-flag vessels required to request authorization to enter. Contracting parties are required to deny either entry or services to vessels engaged in IUU fishing, or if the fish on board were not taken in accordance with SEAFO requirements. Any foreign vessel in a designated port is subject to inspection, while there are reporting requirements for in-port trans-shipments.

Precautionary TACs have been gradually introduced for each target species, the first coming into effect in 2008, and subsequently revised either annually or biennially (Table 8.3). Some are for specified management areas, exerting a limitation on existing fisheries and the opportunity to develop new fisheries elsewhere. Alternatively, as in the case of toothfish, these can maintain an existing fishery in Subarea D while preventing expansion to other parts of the convention area.

An evolving series of additional measures have restricted high seas bottom fishing in order to protect vulnerable marine ecosystems (VMEs) in the southeast Atlantic (Table 8.3). This provides a broadly comprehensive system, defining existing fishing areas, establishing area closures and setting an exploratory protocol for fishing outside the defined existing areas. Additionally, it provides a protocol for encounters with VME-indicator organisms, complete with the necessary identification guide for these, as and when impact assessments are required (see van Zyl *et al*., 2016 for details). Of the numerous measures, the area restrictions likely have the most immediate consequences for fisheries. These have varied over time and continue to do so but, in 2016, 515 495 km^2 of the region's high seas seabed lay in defined existing fishing areas (Figure 8.4). A total of 503 815 km^2 of the SEAFO convention area lay within the closures designed to protect known or likely VMEs, while the remaining 14 646 380 km^2 was subject to the exploratory protocol. The Japanese fishery for Patagonian toothfish operated under that protocol during 2012–2014, which led to an expansion of the defined existing fishing area

FIGURE 8.4
Map of existing fishing areas, VME closures and other areas where additional regulations apply in 2018



Source: FAO, 2019b.

TABLE 8.3
Conservation measures adopted by SEAFO from 2005 to present that are pertinent to high seas bottom fisheries

In force	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Effort and TAC restrictions														
TACs			10/07	→	16/09	20/10	→	23/12	27/13	28/14	31/15	32/16	→	→
Other measures including closures														
SEAFO System									2013	2014	2015	2016	2017	→
Port state measures	02/05	→	09/07	→	→	21/11	→	→	↑	↑	↑	↑	↑	↑
Monitoring of Fisheries (VMS, Scientific Observers)	01/05	→	→	→	→	→	→	→	↑	↑	↑	↑	↑	↑
IUU list		08/06	→	→	→	→	→	→	↑	↑	↑	↑	↑	↑
Transshipment		03/06	→	→	13/09	→	→	→	↑	↑	↑	↑	↑	↑
Gear - Retrieving lost / Marking						19/10	→	→	↑	↑	↑	↑	↑	↑
Protection of VMEs		06/06	→	→	→	18/10	→	→	→	29/14	30/15	→	→	→
Bottom fishing activities			(11/07)	12/08	17/09	→	22/11	24/12	26/13	29/14	30/15	→	→	→
Conservation of sharks		04/06	→	→	→	→	→	→	→	→	→	→	→	→
Reducing seabird bycatch		05/06	→	→	15/09	→	→	25/12	→	→	→	→	→	→
Reducing turtle mortality					14/09	→	→	→	→	→	→	→	→	→

(): measure on "Opening of closed areas"

→ = carried over to next year

↑ = measure repealed and included in similar form in the SEAFO *System of Observation, Inspection, Compliance and Enforcement* produced by SEAFO annually

Blank cell indicates no measure

Note that not all measures were in force for the complete year.

Source: see http://www.seafo.org/Management/Conservation-Measures for details.

of 18 562 km^2 in 2014 and an additional 9 136 km^2 in 2016, though for longline gear only (Table 8.3; SEAFO CM 30/15).

Other conservation measures include requirements to minimize the environmental impacts of fishing. SEAFO CM 25/12 specifies measures to protect seabirds, including the use of tori poles and bird-scaring lines when longlining south of 30° S, or when trawling anywhere in the convention area; this is in addition to a requirement to set only at night and with restrictions on deck lights when longlining (with exceptions for those who comply with complex protocols for ensuring that lines sink quickly), and restrictions on the dumping of offal by both longliners and trawlers. SEAFO CM 04/06 contains requirements to ensure the full utilization and reporting of any sharks caught, while SEAFO CM 14/09 commits parties to implementing the FAO Guidelines to Reduce Sea Turtle Mortality in Fishing Operations. SEAFO recommends that directed fishing for deepwater sharks (SEAFO Recommendation 1/08) and the use of gillnets be banned in the SEAFO convention area (SEAFO Recommendation 2/09).

HIGH SEAS BOTTOM FISHERIES

Development from the hake fishery

The high seas bottom fisheries of the southeast Atlantic have been a minor, and rather recent, development built on fisheries in areas that now fall within EEZs. A wide variety of species have been exploited in coastal waters, not only along the African continental shelf and slope but also around the islands of the British Overseas Territory. It was, however, the trawl fisheries for hake which led to offshore development.

The South African hake fishery began around 1900, expanded gradually after 1918 and faster from 1945, with annual catches exceeding 100 000 tonnes by the mid-1950s. From 1962 local trawlers were joined by the distant-water fleets of Spain and Japan. The latter soon discovered the rich resources further north, off Namibia. The fleets of other states followed, particularly that of the former USSR, which reported exploratory catches of southeast Atlantic hake from 1961 and commercial-scale landings from 1965 (FAO, 2019a). The fishing effort of the former USSR increased in the region following its displacement, in 1968, from the hake resource on Patagonian Shelf and its fishing-out of the rockcod around South Georgia in 1969–1971. The southeast Atlantic regional hake catch exceeded 1 100 000 tonnes in 1972, more than half of it taken by trawlers from the former USSR (in a fishery which also took large quantities of pelagic horse mackerel), while the Spanish fleet accounted for much of the remainder. The former USSR was primarily concerned with the quantity of fish landed and its fleet took large quantities of juvenile hake. The Spanish market, by contrast, emphasized quality and hence larger fish. The latter demand encouraged fishing below 500 m depth from the 1990s.

South Africa declared its EEZ in 1977 and thereafter almost eliminated foreign-flag effort from that zone. However, no EEZ off Namibia was internationally recognized until after independence in 1990, leaving the most productive grounds open to international exploitation until that year. The hake fisheries have continued through the past quarter-century but entirely under national jurisdiction (Payne and Punt, 1995; Gordoa *et al.*, 1995; Paterson *et al.*, 2013; Durholtz *et al.*, 2015; Wilhelm *et al.*, 2015).

Alfonsino and pelagic armourhead trawl fisheries

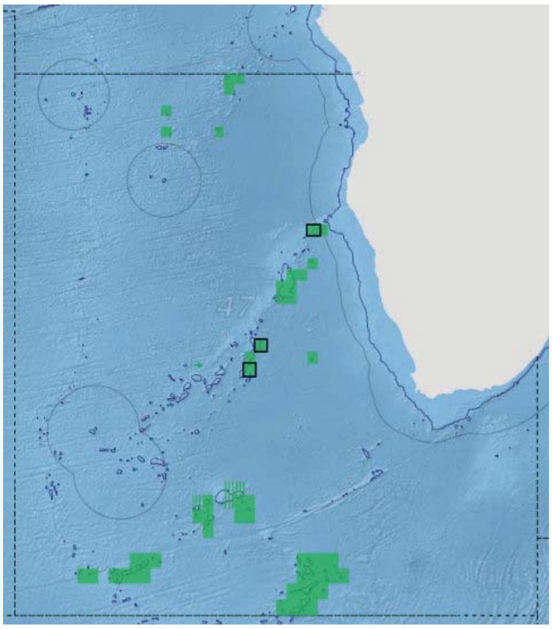
These species are caught mainly by bottom trawls, and to a lesser extent by deep midwater trawls (Table 8.4). These two gears fish in a similar way, as the bottom trawl does not involve extensive ground contact and the midwater trawls are fished close to the sea floor, touching around 10 percent of the tows (Tingley, 2014). The Spanish fleet took small amounts of both species on longlines. The primary, recent fishing grounds for alfonsino were on and around Valdivia Bank and towards the northern end of Walvis Ridge adjacent to the EEZ boundary (Figure 8.5), whereas pelagic armourhead

TABLE 8.4
Specifications of trawl gears used by Republic of Korea for catching alfonsino and pelagic armourhead

Gear	Specification	Hampidjan net	Manufactured net	Midwater net
Trawl Net	Purpose	Bottom trawl	Bottom trawl	Midwater trawl
	net length overall (m)	66	66.9	210.0
	head rope (m)	48	59.0	93.6
	ground rope (m)	50	77.9	93.6
	net height (m)	5.5	5.5	70
	net width (m)	30	200	240~260
	net girth (m)	100	83	816
	mesh size (mm)	120	120	120
Otter board	type	VRS-TYPE	VRS-TYPE	VRS-TYPE
	material	Steel	Steel	Steel
	size (mm)	2 300 x 4 030	2 750 x 4 900	1 854 x 3 818
	weight (kg)	3 930	4 320	2 000
	underwater weight (kg)	2 619	2 473	1 145

Source: SEAFO, 2017a.

FIGURE 8.5
Distribution of alfonsino catches in the high seas of the southeast Atlantic in 2010–2013



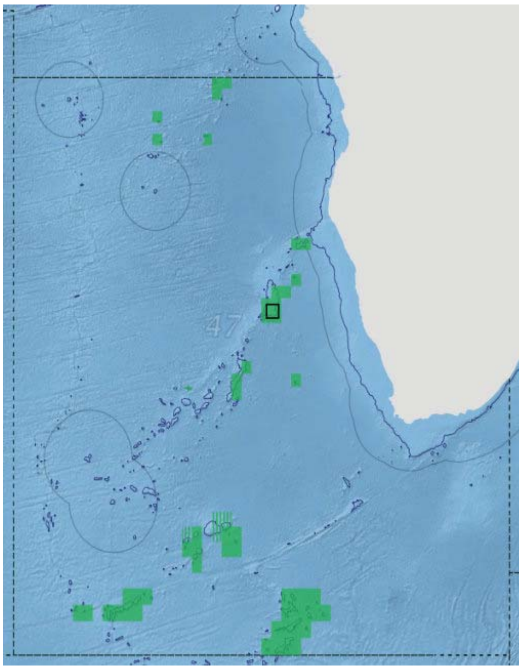
☐ = location of catches ■ = bottom fishing areas

Source: redrawn from SEAFO, 2017a.

tended to be caught on Walvis Ridge east of Valdivia Bank, and thus somewhat separated from the alfonsino fisheries (Figure 8.6). Both can be bycatch species in fisheries targeting the other, together with blackbelly rosefish, imperial blackfish, oilfish, Cape bonnetmouth, and silver scabbardfish.

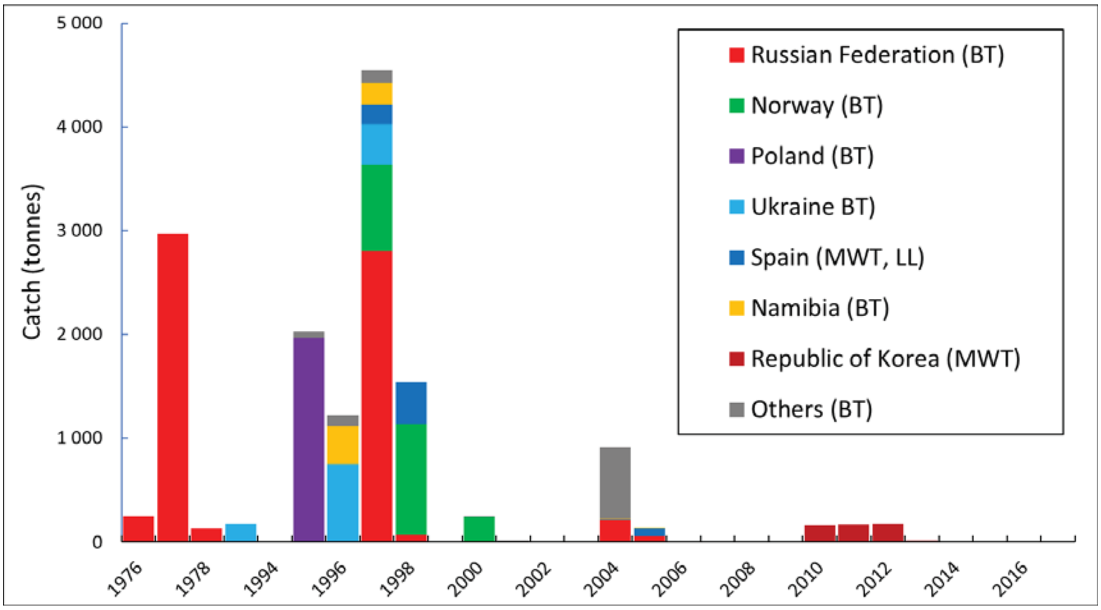
Bottom fishing in what are now the high seas of the southeast Atlantic began with the expansion of the former USSR seamount fishery into the region in 1976–1979, which targeted alfonsino and pelagic armourhead. The fishery only resumed in 1993, or at least was not reported until then. Over the following 20 years a number of attempts

FIGURE 8.6
Distribution of pelagic armourhead catches in the high seas of the southeast Atlantic in 2010–2013



☐ = location of catches ■ = bottom fishing areas
Source: redrawn from SEAFO, 2017b.

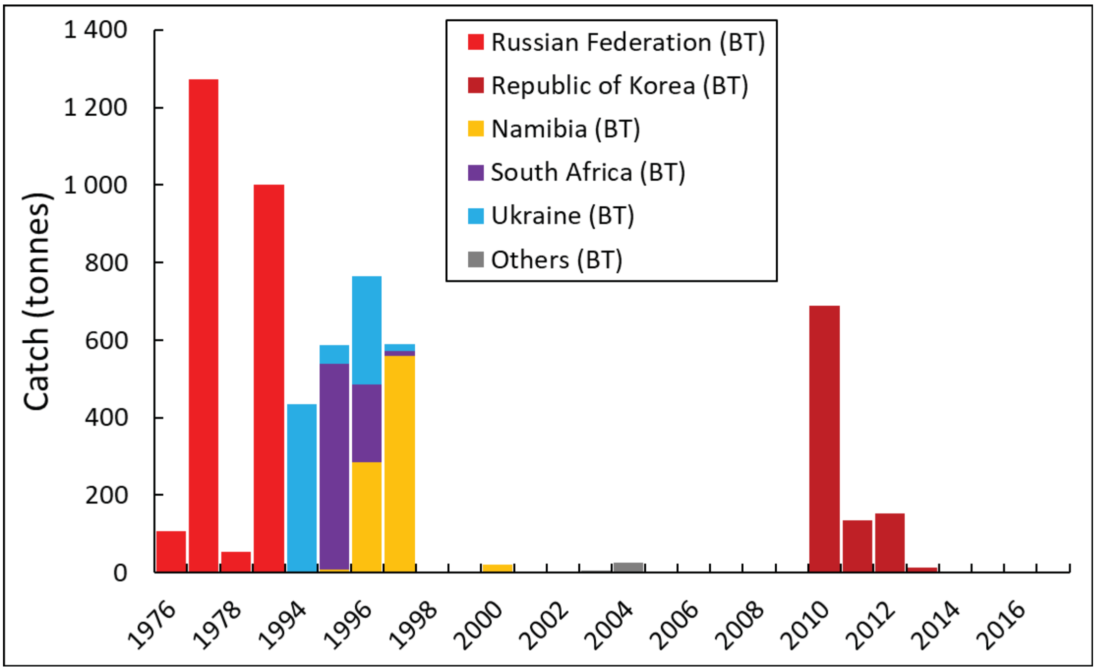
FIGURE 8.7
Catches of alfonsino in the high seas of the southeast Atlantic in 1976–2017



BT = bottom trawl; MWT = midwater trawl; LL = longline
Source: SEAFO, 2017a.

were made by various nations to develop fisheries – or, at least, landings were recorded. These catches were apparently often taken by distant-water vessels as they steamed past the seamounts towards other, more productive grounds. The main periods fished were 1994–1997, 2004–2005 and 2010–2012, with very low catches in the intervening years (Figure 8.7 and Figure 8.8).

FIGURE 8.8
Catches of pelagic armourhead in the high seas of the southeast Atlantic in 1976–2017



BT = bottom trawl
Source: SEAFO, 2017b.

Alfonsino

Reported landing (or catches) of alfonsino have fluctuated greatly with the former USSR/ Russian Federation taking a total of 6 482 tonnes, mainly in 1977 and 1997. Poland caught almost 2 000 tonnes in 1995, Ukraine over 1 300 tonnes in the 1990s, and Norway over 2 100 tonnes in 1997–2000. There was a slight resurgence in 2004, but this was followed by low catches the following year. The only recent fishery was operated by the Republic of Korea using midwater trawls in 2010–2013 catching around 160 tonnes each year for the first three years but only 13 tonnes in 2013. There have been no reported catches by any country from the high seas since 2015 (Figure 8.7; SEAFO, 2017a).

The recent history of this fishery, with catches from just 2010–2012, does not allow for any kind of abundance estimate or stock trend using catch per unit of effort (CPUE) data. A simple harvest control rule was applied based on the average of three years of catches, less 20 percent to allow for uncertainty. This gives catch advice of 132 tonnes per year. SEAFO first adopted an annual TAC limit for alfonsino in 2010 with a catch limit of 200 tonnes for the convention area which has remained in effect. A limit of 132 tonnes for Division B1 was introduced in 2015, which was decreased to 135 tonnes in 2017 and 2018. However, there has been no fishing since 2013 and the TAC is not utilised.

Pelagic armourhead

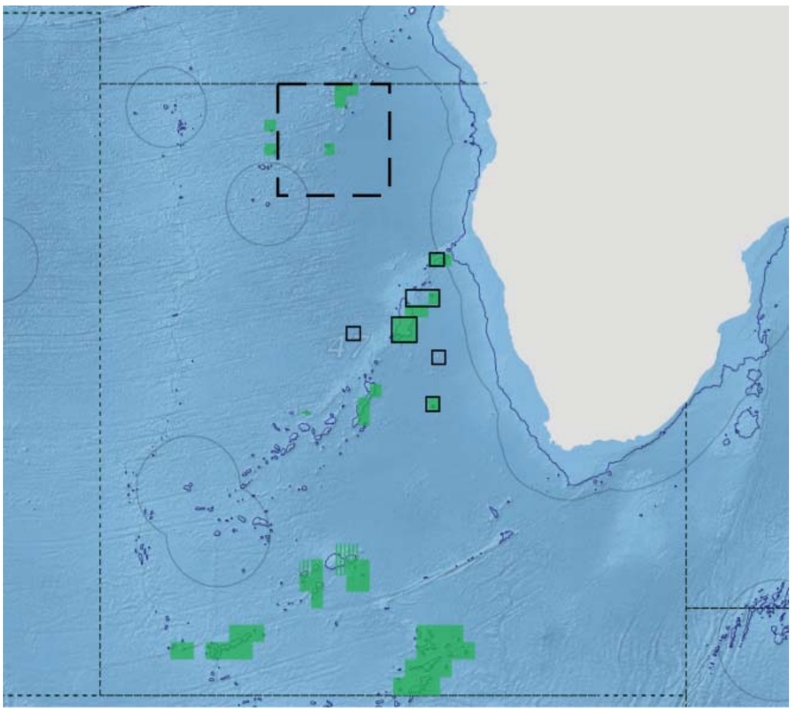
The fishery for pelagic armourhead, though targeted separately in different areas, has followed a similar pattern of exploitation to alfonsino, mainly because both species can be exploited with the same gears. The highest catches were by the former USSR/Russian Federation fleets in 1977 and 1993, followed by lower catches by various countries from 1994–1997. After which there was virtually no fishery or reported catches until those of the 2010–2013 period by the Republic of Korea, using deep midwater trawls. No significant caches have been reported since and the fishery has ceased (Figure 8.8; SEAFO, 2017b).

The assessment of pelagic armourhead was also based on information from 2010–2012 and based on a depletion model. Information from 2013 suggests a catch of 13 tonnes was not used. The catch declined from 688 tonnes in 2010 to 135 tonnes in 2011, and was similar in 2012 at 152 tonnes. The peak CPUE in 2010 was in the 7–20 tonnes per hour range, whereas the highest observed in 2011 and 2012 was 2–3 tonnes per hour. On board observers noted that CPUE in 2011 was only 16 percent of that observed in 2010. The view of the assessment is that the stock is depleted and a calculation gave an estimate future annual yield of 128 tonnes. SEAFO first adopted an annual TAC limit for pelagic armourhead in 2015 and 2016 with a catch limit of 143 tonnes for the convention area, which was decreased to 135 tonnes in 2017 and 2018. However, there has been no fishing since 2013 to refine the assessment and the TAC is not utilized.

Orange roughy trawl fishery

A bottom-trawl fishery for orange roughy within the Namibian EEZ started in 1994, targeting winter aggregations, and in the high seas from 1995. Catches in the Namibian EEZ rose very quickly and peaked at 17 381 tonnes in 1996 but thereafter declined to a few hundred tonnes in 2007 and effectively zero thereafter, though 236 tonnes were taken in 2016. Catches in the high seas by Namibia and South Africa were taken from Valdivia Bank and Ewing Seamount in Division B1, whereas the

FIGURE 8.9
Distribution of orange roughy catches in the high seas of the southeast Atlantic in 1998–2005

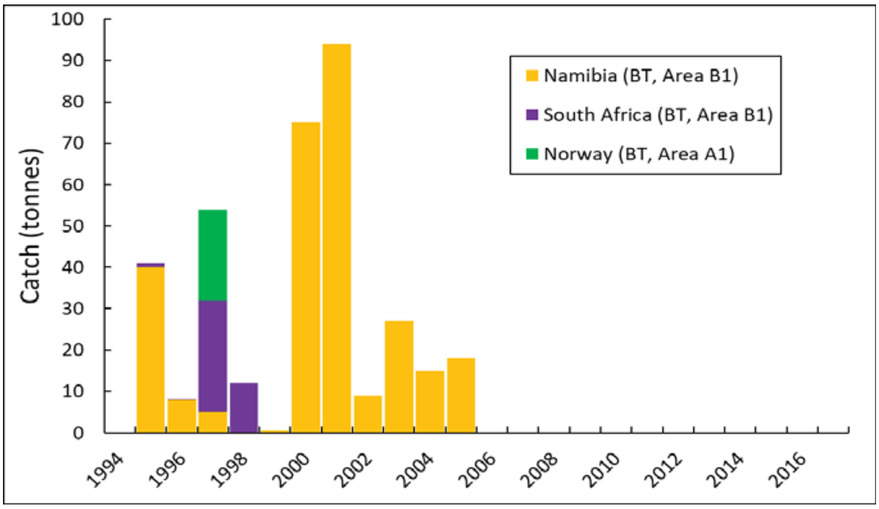


☐ = location of catches by Namibia and South Africa ⌐┘ = location of catches by Norway ■ = bottom fishing areas
Note that some of these catches occurred prior to the footprint being adopted.
Source: redrawn from SEAFO, 2017c.

Norwegian catches came from Division A1 northeast of St. Helena (Figure 8.9). However, the high seas catches have been less than 1 percent of the southeast Atlantic EEZ catches. Namibia fished for orange roughy in the high seas from 1995 to 2005, taking a maximum of 94 tonnes in 2001, but normally much less. Norway fished only in 1997 and South Africa in 1995–1998, though annual caches were less than 30 tonnes (Figure 8.10). Bensch *et al.* (2009) noted that the Cook Islands had reported two vessels under their flag fishing for roughy in the high seas of the region during 2003–2006 but catches were unknown. No catches of orange roughy taken from the high seas after 2005 have been reported to SEAFO. Bycatch species have been recorded as alfonsino, pelagic armourhead, black cardinal fish, and various oreo dory and deep-sea shark species (SEAFO, 2017c).

An assessment has been attempted on the historical data sets using CPUE trends which showed a catch rate of 2 tonnes per trawl in 1995 and a decline to almost zero the following year, before stabilizing to 0.2–90.4 per trawl for 2000–2005. The effort was quite variable during this period, with the annual number of tows being 16–327, and no assessment could be made. SEAFO have set a zero TAC for Division B1 and a 50 tonne TAC for the remainder of the convention area. Those were maintained through to 2018, except that from 2015 there was an additional 4 tonnes bycatch allowance in Division 1B (SEAFO, 2017c).

FIGURE 8.10
Catches of orange roughy in the high seas of the southeast Atlantic in 1994–2017

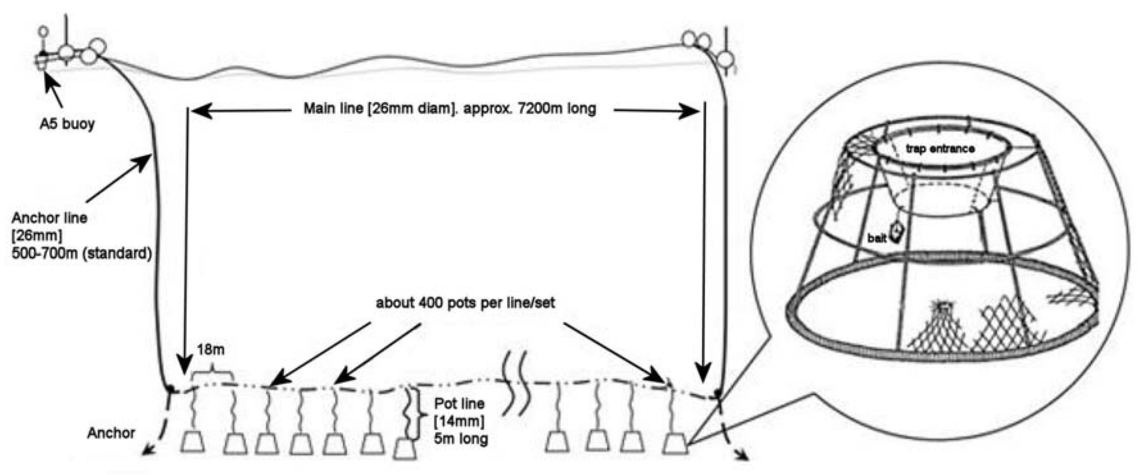


BT = bottom trawl
Source: SEAFO, 2017c.

Red crab pot fishery

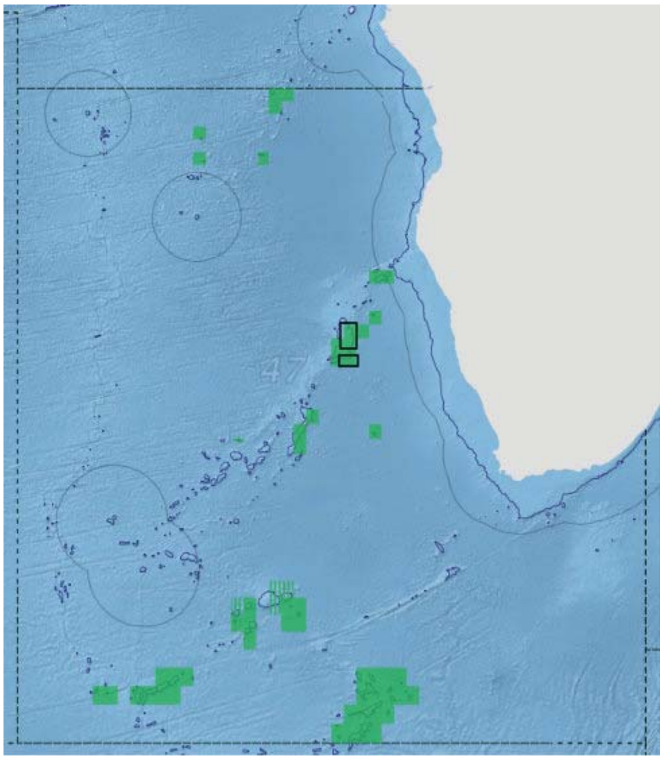
A pot fishery for red crab, predominantly *Chaceon erytheiae*, has been conducted in the high seas of the southeast Atlantic since 2001 (Figure 8.11). The main fishing grounds are at two sites on the Valdivia Bank (Division B1) at depths of 280–1 150 m (Figure 8.12). More continuous effort was undertaken by Japan in 2005–2010 and Namibia in 2011–2014, otherwise fishing has been intermittent; the only higher catches were taken by the Republic of Korea in 2015, Japan in 2017 and Namibia in 2018. Spain and Portugal have also occasionally fished for crab. When the effort is made, catches seem to be stable at around 200 tonnes per year. Peak catches occurred in 2006 and 2007 reaching 389 tonnes and 808 tonnes respectively. Bycatch is very low and has been limited to catches of around one tonne of king crab in 2015 only (Figure 8.13).

FIGURE 8.11
Deep-sea crab fishing gear and the Japanese beehive pot



Source: SEAFO, 2017d.

FIGURE 8.12
Distribution of red crab catches in the high seas of the southeast Atlantic in 2010–2015

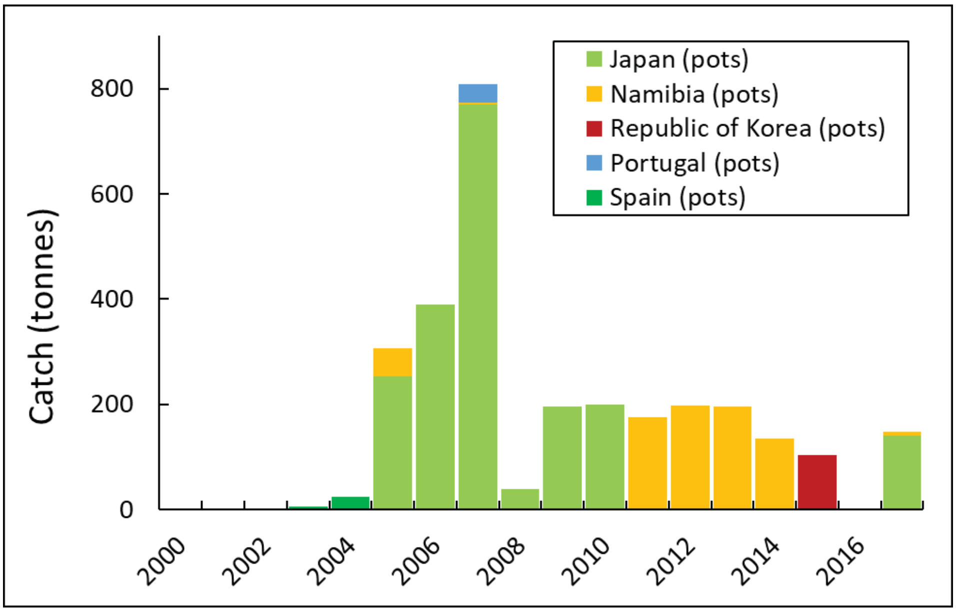


☐ = location of catches ■ = bottom fishing areas

Source: redrawn from SEAFO, 2017d.

SEAFO first set a TAC in 2008 of 200 tonnes for Division B1 and a 200 tonnes TAC for the remainder of the convention area. This remained in effect until the TAC for Division B1 was reduced to 190 tonnes in 2016 and further to 180 tonnes in 2017–2018; the TAC for the other areas remained unchanged (SEAFO, 2017d). SEAFO closed an area south of Valdivia Bank from 2016 to protect VMEs – mainly scleractinian corals

FIGURE 8.13
Catches of deep-sea red crab in the high seas of the southeast Atlantic in 2000–2017



Source: SEAFO, 2017d.

–from significant adverse impacts caused by mobile fishing gears, though fishing with pots and set longlines is permitted. ROV surveys have found lost pots and ropes at Valdivia, though more were seen at Vema seamount to the south, indicting that crab fishing has occurred there in the past (SEAFO, 2015).

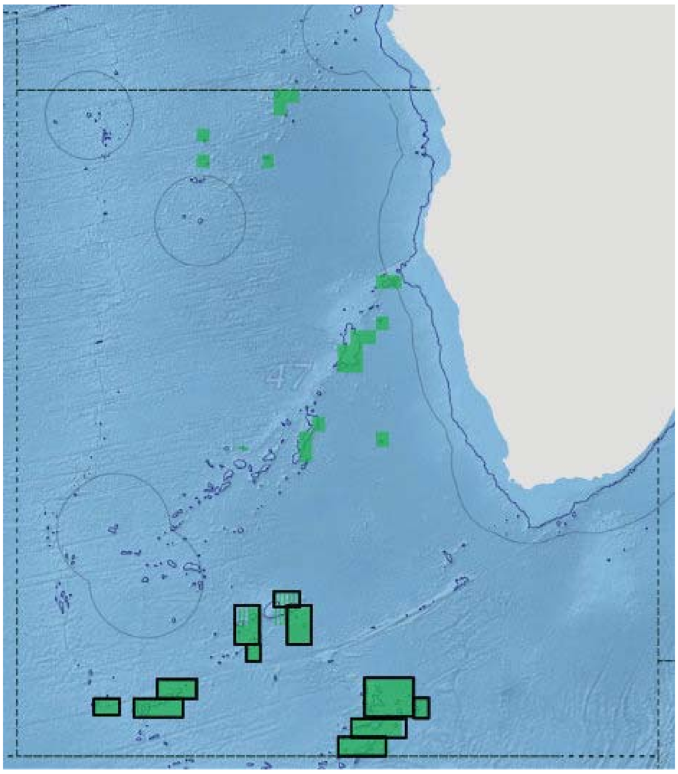
PATAGONIAN TOOTHFISH LONGLINE FISHERY

The deep longlining for adult Patagonian toothfish which was developed in Chilean waters in the 1980s spread among the sub-Antarctic islands during the following decade. Circumglobally, the range of the resource extends northwards, beyond the boundary of the Southern Ocean, into the Pacific, Atlantic and Indian Oceans. It has been confined to seamount chains southward of 40° S, particularly the Discovery seamounts of SEAFO Sub-area D and the Meteor Seamounts in Division D1 (Figure 8.14). The stock status is unknown, but the same species is caught in CCAMLR Subarea 48.6 immediately to the south, together with the related Antarctic toothfish. It is likely that in recent years the fishery operates in synergy with the neighbouring CCAMLR research fishery undertaken by Japan and South Africa (CCAMLR, 2018), though only Japan currently fishes for toothfish in the SEAFO area.

Spanish vessels fished with longlines designed to suspend the hooks above the seabed, which was only contacted by weights, set at intervals along the hookline (Figure 8.15a). However, in the Japanese variant multiple bunches of hooks are clipped to the droplines.

The Japanese fleet started fishing in 2003 and has since fished every year. The Japanese fishery also uses a gear in which the mainline is held above the seabed by floats, connected by droplines to weights on the seabed (Figure 8.15b). Catches during the 2004–2011 period averaged nearly 140 tonnes per year, but they started to decline thereafter to around 10 tonnes per year in 2017. There has been some fishing by vessels flagged to Spain, South Africa and the Republic of Korea, with the odd year of high catches (Figure 8.16; SEAFO, 2017e).

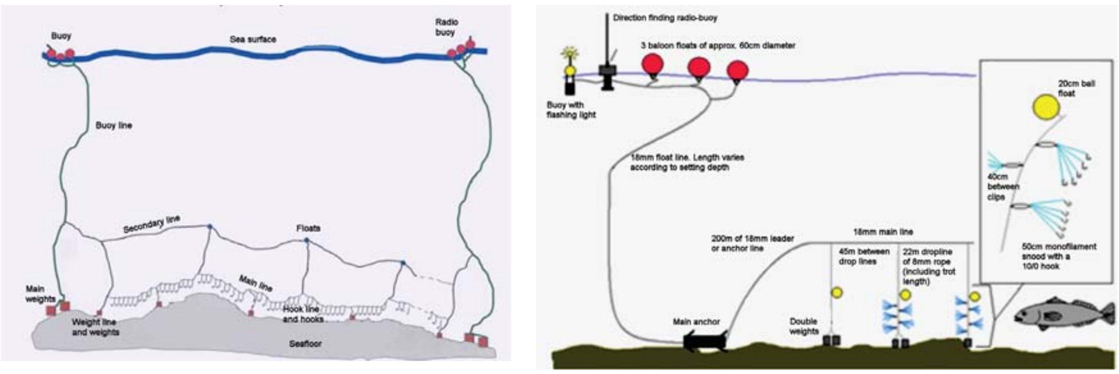
FIGURE 8.14
Distribution of toothfish catches in the high seas of the southeast Atlantic in 2010–2014



☐ = location of catches ■ = bottom fishing areas

Source: redrawn from SEAFO, 2017e.

FIGURE 8.15
Longline gear used to catch toothfish showing: (a) Spanish longline system, and (b) Japanese trotline system

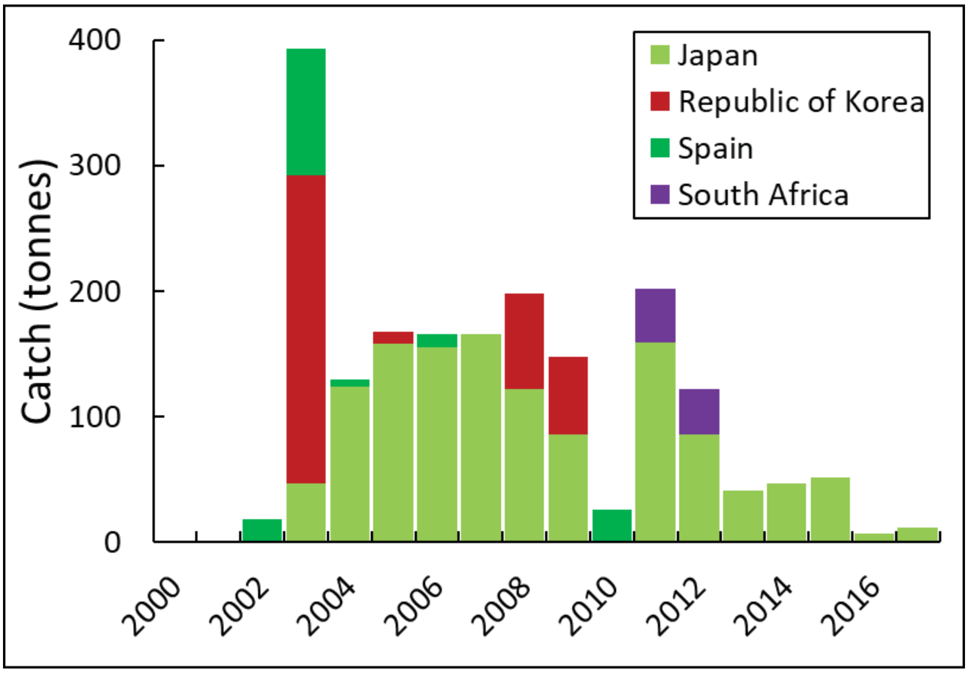


(a) (b)

Source: SEAFO, 2017e.

Bycatches, primarily of macrourid grenadiers but also blue antimora and a variety of other species, have exceeded 20 tonnes in some years but have usually been much smaller. More than 50 kg of benthos – the vast majority of which were gorgonians – were taken by toothfish gear in 2010, but that figure fell to 5 kg or less in 2013 and 2014. There are

FIGURE 8.16
Catches of Patagonian toothfish in the high seas of the southeast Atlantic



Source: SEAFO, 2017e.

records of only three seabird fatalities, all from a Japanese longline vessel fishing during daylight hours.

There is no agreed stock assessment for this stock of Patagonian toothfish. SEAFO first adopted an annual TAC of 260 tonnes for Patagonian toothfish in 2008–2009 for the convention area. This was subsequently adjusted over the following years, as follows: 200 tonnes in 2010; 230 tonnes in 2011–2013; 276 tonnes in 2014; 276 tonnes in 2015; 264 tonnes in 2016; and 266 tonnes in 2017–2018. From 2014 the TAC applied to Sub-area D only, with no allowance in the rest of the convention area. The catch since 2013 has been well below the TACs adopted.

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9. Southwest Atlantic Ocean

FAO Major Fishing Area 41

SUMMARY

The southwest Atlantic is characterized by an extremely wide continental shelf in the south that receives cold, nutrient-rich water from the South Antarctic Polar Current. This gives rise to a productive pelagic and benthic fishery dominated by Argentine shortfin squid and Argentine hake. The squid was originally fished with bottom trawls, though nowadays midwater trawls and jigging predominate. The hake is fished, along with other species, with bottom trawls.

Only a small portion of the continental shelf extends into the high seas, and it has been exploited by many states. As such, catches in the high seas are not separately recorded and are difficult to enumerate. Many distant fleets have in the past been granted licences to fish in national waters, and this adds to the difficulty of separating catches. Estimated catches in the high seas were not available for 2016, so catches from 2014 were used. The total reported catch for the whole of the southwest Atlantic in 2014 was 952 000 tonnes of demersal finfish, 976 000 tonnes of cephalopods, 212 000 tonnes of pelagic finfish, plus some 276 000 tonnes of other species groups that are not fished in the high seas (FAO, 2019). Estimated catches in the high seas with bottom trawls and longlines for 2014 amounted to some 58 000 tonnes of demersal finfish and 15 000 tonnes of squid, which is 2–5 percent of the total catch; this suggests the enormity of the catches taken within national waters (Table 9.1). There have been small fisheries on the seamount chains, mainly in the northern half of the region, with some catches of alfonsino recorded, but these are not believed to be active currently.

TABLE 9.1
High seas bottom fisheries catches (tonnes) in the southwest Atlantic in 2014 and 2016

Gear	Principal grounds	Flag states	Target species	2014 catch	2016 catch
Bottom trawl	Patagonian Shelf	Spain	longtail southern cod	24 000	10 319
			Argentine hake	19 000	19 000
			Argentine shortfin squid	15 000	3 451*
			other finfish	3 000	3 000
Bottom trawl	Patagonian Shelf	Republic of Korea	various[1]	< c.7 000	
Bottom trawl	Patagonian Shelf	Argentina	Argentine shortfin squid	23	
			Patagonian grenadier	18	
			Argentine hake	9	
Bottom trawl	Patagonian Shelf	Argentina	Patagonian scallop	26	
Longline	Various deepwater	Republic of Korea	Patagonian toothfish	≤1 800	
Longline	Various deepwater	Ukraine	Patagonian toothfish	141	

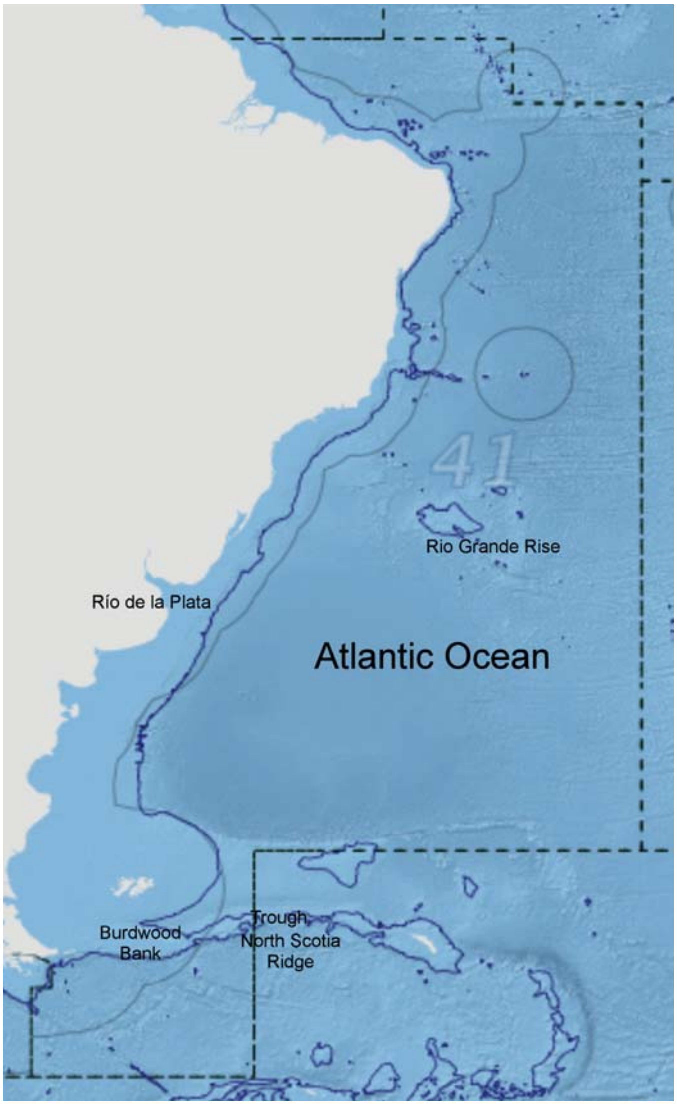
[1] Estimated from total southwest Atlantic catch minus squids (mainly jigging), toothfish, large pelagic species, elasmobranchs, other molluscs (FAO, 2019).

GEOGRAPHIC DESCRIPTION

For the purposes of this document the southwest Atlantic Ocean comprises the sea area between the 20° W meridian and the coastline of South America, stretching northward to 10° S, and southward to 60° S. South of Cape Horn, the western boundary is set at 67° 16’ W (Figure 9.1). The boundary of the region’s high seas is taken as lying 200 nautical miles from coastal baselines.

The continental shelf is narrow in the north but broadens southwards, growing wider off Patagonia and exceptionally so in the latitudes of the Strait of Magellan and Tierra del Fuego. In more southerly latitudes the continental slope is relatively flat, such that there is a very broad swath of seabed between 200 m and 2 000 m depth. In the extreme south, two geomorphological features reach eastward, separated by a deep trough. The Patagonian shelf extends to a maximum width some 850 km east

FIGURE 9.1
Map of the southwest Atlantic Ocean



200 nautical mile arcs, 2 000 m isobath (GEBCO), FAO fishing areas.

Source: FAO VME Database, Mercator projection.

of the Falkland Islands (Malvinas)[1] and is known as the Falkland (Malvinas) Plateau. Immediately to the south, and separated by the Falklands (Malvinas) Trough, Burdwood Bank projects eastwards from Tierra del Fuego at 55° S, merging with the North Scotia Ridge, part of the Scotia Arc, most of which lies within the CCAMLR convention area. The area of the high seas at fishable depths in the southwest Atlantic is relatively small (Table 9.2).

There are several seamount chains extending eastwards between the equator and 30° S, including those of Brazil's Trinidade and Martim Vaz archipelago. The extensive Rio Grande Rise lies south of 30° S.

TABLE 9.2
Area statistics for the southwest Atlantic Ocean

Geographical area	Surface area (km²)
Total sea area	13 929 000
Area of high seas[1]	10 315 000
Area of high seas shallower than 200 m	9 000
Area of high seas shallower than 400 m	15 000
Area of high seas shallower than 1 000 m	53 000
Area of high seas shallower than 2 000 m	188 000

[1] Taken as the 200-nautical-mile limit.

ECOSYSTEMS AND RESOURCE SPECIES

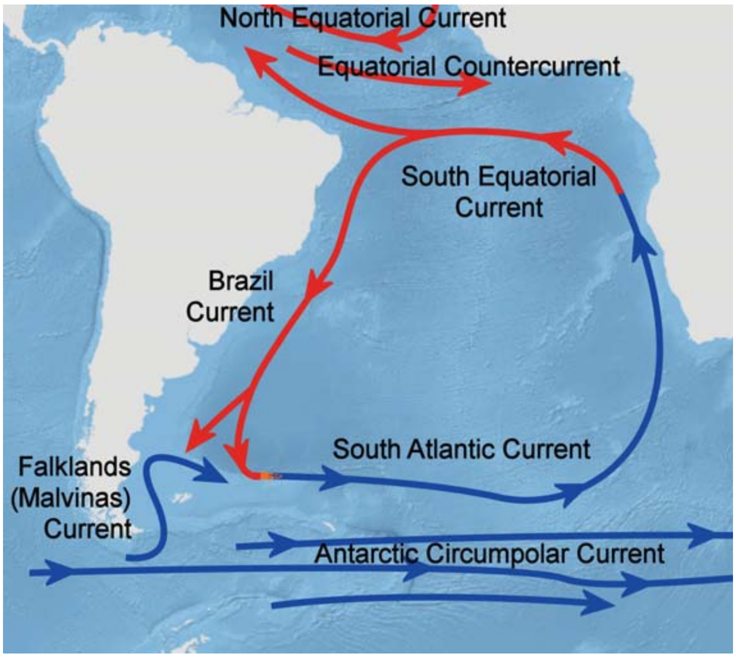
The ecosystems of the southwest Atlantic are dominated by contrasting warm and cold western-boundary currents flowing over and past extensive continental shelf areas (Figure 9.2). The southbound Brazil Current forms the western part of the anticlockwise South Atlantic gyre receiving warm relatively nutrient poor waters from the westbound South Equatorial Current. The cold, nutrient-rich Falklands (Malvinas) Current dominates the oceanography of the region's high seas fishing grounds, where it extends from the sea surface to the sea floor. The current is a branch of the eastward-flowing Antarctic Circumpolar Current, which turns northward after passing Cape Hornand divides around the Falkland Islands (Malvinas); the weaker western branch contributes to the waters of the Patagonian Shelf, while the stronger eastern branch follows the continental margin northward to the latitude of the Río de la Plata; there it meets the Brazil Current and the waters of both turn southeast as a complex eddy field. These eventually join the eastbound Antarctic Circumpolar Current.

The whole Patagonia shelf region is very productive in both the benthic and pelagic zones: both have major fisheries, including where resources straddle the EEZ/high seas boundary. Fishing in the region is mostly confined to depths of less than 500 m, which limits the high seas fishing grounds to a small area between 41° 50'–42° 30' S and a larger one between 44° 45'–47° 20' S (Portela *et al*., 2002a). However, the longline fishery for Patagonian toothfish, which operates at much greater depths, exploits high seas grounds across a wider range of latitudes, where the continental slope extends beyond the 200-nautical-mile limit. By far the majority of the region's high seas bottom fishing has occurred in those areas of shelf and slope north of approximately 48° S.

Otherwise, some seamounts attain potentially fishable depths in the Trinidade/Martim Vaz chain, the Rio Grande Rise, and approximately 250 km of the North Scotia Ridge (between the outer limit of national jurisdiction at approximately 54° W, and the boundary of the CCAMLR convention area at 50° W). Parts of each of those features

[1] A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas)" - see United Nations document ST/CS/SER.A/42. Reference made to the Falkland Islands (Malvinas) is geographical in nature and does not prejudge the questions related to the territorial status of these islands.

FIGURE 9.2
South Atlantic gyre and associated currents of the south Atlantic Ocean



Source: FAO VME Database, currents added.

have been fished. The 2 000 m contour around the Falkland Islands (Malvinas) barely extends into the high seas – though some fishing for Patagonian toothfish may occur more than 200 nautical miles northeast of the archipelago. Finally, at its eastern end the Falklands (Malvinas) Plateau rises into potentially fishable depths at Ewing Bank. Most of that feature lies in the CCAMLR convention area, and all of it is significantly deeper than 1 000 m – but there may be some toothfish longlining on its northern extremity in southwest Atlantic waters (Barton *et al*., 2004).

There are a wide range of species caught with gears that fish on or close to the sea floor (Figure 9.3).

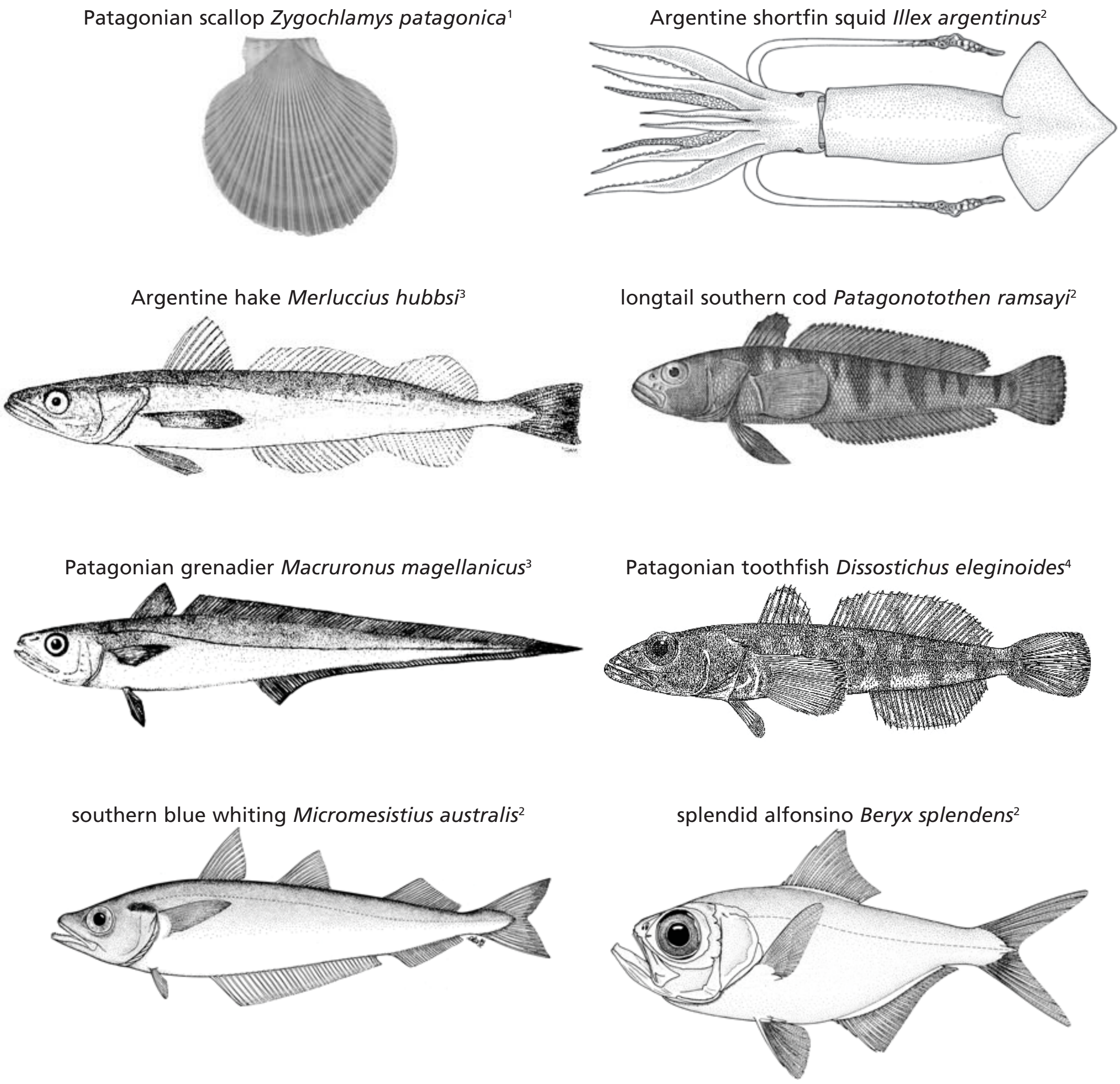
Squid

The Argentine shortfin squid and Patagonian squid yield substantial catches in the southwest Atlantic though only the former supports a directed fishery in the high seas. This species is represented by at least three separate populations; two of which are widespread across the Patagonian Shelf in summer (Brunetti *et al*., 1998a). By April (early in the austral autumn), the autumn-spawning "southern Patagonian stock" concentrates on the continental slope east of Patagonia, and then migrates northwards into deeper water to spawn and die. The high seas fishery exploits this stock. As is normal with squids that have single-year life cycles, there has been high inter-annual variability in both biological and fishery production (Brunetti *et al*., 1998b; Barton *et al*., 2004; Arkhipkin *et al*., 2015a).

Hake

Merluccid hakes constitute by far the greatest demersal resource of the Patagonian Shelf, and Argentine hake, which forms multiple stocks, predominates. Sometimes called "common hake" in the region, it is primarily found in shelf waters, from off Tierra del Fuego northwards as far as Brazilian waters. A considerable amount of research has been dedicated to these resources, particularly Argentine hake, the biology of which is becoming well-known (Arkhipkin *et al*., 2015b; Irusta *et al*., 2016). There is

FIGURE 9.3
Principal demersal resource species of the high seas of the southwest Atlantic Ocean



Source:
[1] Patagonian scallop. Sustainable Fisheries Partnership. (2019). FishSource. [online] Available at: www.fishsource.org [Accessed 16 Sep 2019].
[2] Food and Agriculture Organization of the United Nations, Original Scientific Illustrations Archive.
[3] Bensch *et al*. (2009).
[4] Fischer and Hureau (1985).

also a resource of Patagonian grenadier (Giussi *et al*., 2016) that is closely related to the hoki (=blue grenadier) that lives around southern Australia and New Zealand.

Other bottom species

Several other species have been the targets of directed bottom fishing on the Patagonian Shelf, all of which are taken at least as bycatch in the trawl fisheries of the high seas area. Southern blue whiting is a planktivore but bottom-associated (Wöhler *et al*., 2004). The biomass of southern blue whiting declined from the early 1990s, and by 2011 was down to some 15 percent of its previous level; overfishing is thought to have been a primary, though perhaps not the only, cause (Laptikhovsky *et al*., 2013). The ecological niche of principal vertebrate planktivore on the southern Patagonian

Shelf appears to have then been occupied by longtail southern cod, though that is a bottom-associated species with a diet that includes benthic prey. It is a member of the family Nototheniidae, which dominates the demersal ichthyofauna of the Southern Ocean. However, unlike its immediate relatives, longtail southern cod has a range extending northwards through the temperate zone of the southwest Atlantic, as far as the Río de la Plata, at shelf and upper-slope depths of up to 500 m. Through the 1990s and into the present century it was taken as a minor bycatch when trawling for other species. By 2010, however, the biomass of longtail southern cod around the Falkland Islands (Malvinas) had risen to approximately 1 000 000 tonnes (Laptikhovsky *et al*., 2013). Other resources include: kingklip, macrourid grenadiers (primarily ridge scaled rattail), tadpole codling and various rajids.

On the few, lower-latitude grounds in the high seas, primarily the Rio Grande Rise, other species fished include alfonsino and Patagonian toothfish; the latter form another important resource, be it the juveniles at continental-shelf depths or the adults primarily on the slopes and deeper ridges (Martínez and Wöhler, 2016). Patagonian toothfish is the only target species of high seas fisheries in the southwest Atlantic that has the biological characteristics usually associated with "deep-sea" resources. And finally, Patagonian scallops are a resource of sedentary molluscs that just extend into the high seas (Lasta and Bremec, 1998; Mauna *et al*., 2008, 2010).

MANAGEMENT OF HIGH SEAS BOTTOM FISHERIES

Multilateral arrangements

There is no multilateral agreement concerning the high seas bottom fisheries of the southwest Atlantic. Vessels fishing in the high seas of the region are still subject to regulation by their respective flag states, with the quantitatively important Spanish fleet also subject to European Union regulations. The Argentine toothfish fleet, for example, is subject to 100 percent observer coverage and a minimum depth limit of 800 m in order to ensure that the catch is primarily adults (Martínez and Wöhler, 2016). Actions by flag states have extended beyond conventional fisheries management to include progress on protecting vulnerable marine ecosystems. A Spanish initiative has led to comprehensive mapping of the high seas area north of 48° S and the delineation of nine area closures – one of them very extensive – which have been implemented for vessels fishing under the Spanish flag (Portela *et al*., 2010, 2015a, 2015b; Río *et al*., 2012; Durán Muñoz *et al*., 2012). Conservation measures applied in waters under national jurisdiction benefit the straddling resources in their entirety, including those portions in the high seas. Argentina similarly instituted a large permanent "Patagonian Closed Area" of 119 000 km^2 in 1997, covering much of the continental shelf between 43–47° S, which was designed to protect both juvenile and spawning-adult Argentine hake. The entire area is closed to trawling (except for certain peripheral parts, which have been opened to shrimp trawlers) and portions have been maintained closed to all fishing (Alemany *et al*., 2013).

Scientific support to management

There is no resource-wide scientific coordination. However, since the resources exploited in the high seas are all straddling stocks, and the overwhelmingly greater portion lies within EEZs, the scientific work undertaken by coastal states and distant-water flag states supports the management of the greater portion of the resources.

DESCRIPTION OF HIGH SEAS BOTTOM FISHERIES

History of demersal fisheries in the southwest Atlantic

The high seas fisheries of the southwest Atlantic all target straddling stocks and have generally taken only a small proportion of overall catches. Yet these account for a major proportion of the world's high seas bottom catch, and currently amount to nearly half of the global total. In order to present that dominant contribution properly, for the purposes of this review, the development of high seas fisheries in the region must be seen in the context of much larger fisheries for the same resources in areas under national jurisdiction. Separation of the high seas catches is problematic, as coastal states have commonly issued licenses to distant-water fleets to fish within their national waters. Detailed and comprehensive information on the fisheries of immediate interest has not been compiled in most cases and there is no forum that compiles data for the high seas. This review can only summarize what is known, while recognizing that the account provided is incomplete in some cases.

Several of the statistical rectangles for the southwest Atlantic straddle the 200-nautical-mile limit and do not permit an estimation of the high seas component of any officially reported catches (CWP, 2018; EuroStat, 2018). Catches in the high seas are known for only a few of the years in the 2003–2014 period and for a few countries (Table 9.3). With information only available for Argentina, Estonia, Republic of Korea, Spain and Uruguay it is difficult to know how representative these catches are. A total of 21 countries reported catches of demersal marine fish and 22 countries for Argentine shortfin squid from the southwest Atlantic in 2000–2015; about half of these fished for only a single or a few years with relatively small catches. The main non-coastal state countries catching demersal marine fish were: Chile, Japan, Portugal, Republic of Korea, Spain, and the United Kingdom of Great Britain and Northern Ireland. The main non-coastal state countries catching Argentine shortfin squid were China, Taiwan Province of China, Japan, Republic of Korea, Spain, and Vanuatu. Japan stopped catching squid in 2007 and has caught only about a hundred tonnes of demersal fish annually since 2012 (FAO, 2019). Known high seas fishing applies only to those countries listed in Table 9.3.

In 2014, the total southwest Atlantic catch reported from FAO Major Fishing Area 41 was 2 416 000 tonnes, of which 1 208 000 tonnes was finfish (including 336 000 tonnes of Argentine hake and 212 000 tonnes of pelagic finfish); 1 020 000 tonnes was molluscs (including 863 000 tonnes of Argentine shortfin squid), and 188 000 tonnes of crustaceans. The estimated total high seas catch in 2014 was probably less than 70 000 tonnes or less than 3 percent of the total southwest Atlantic catch (Table 9.1).

Patagonian Shelf squids

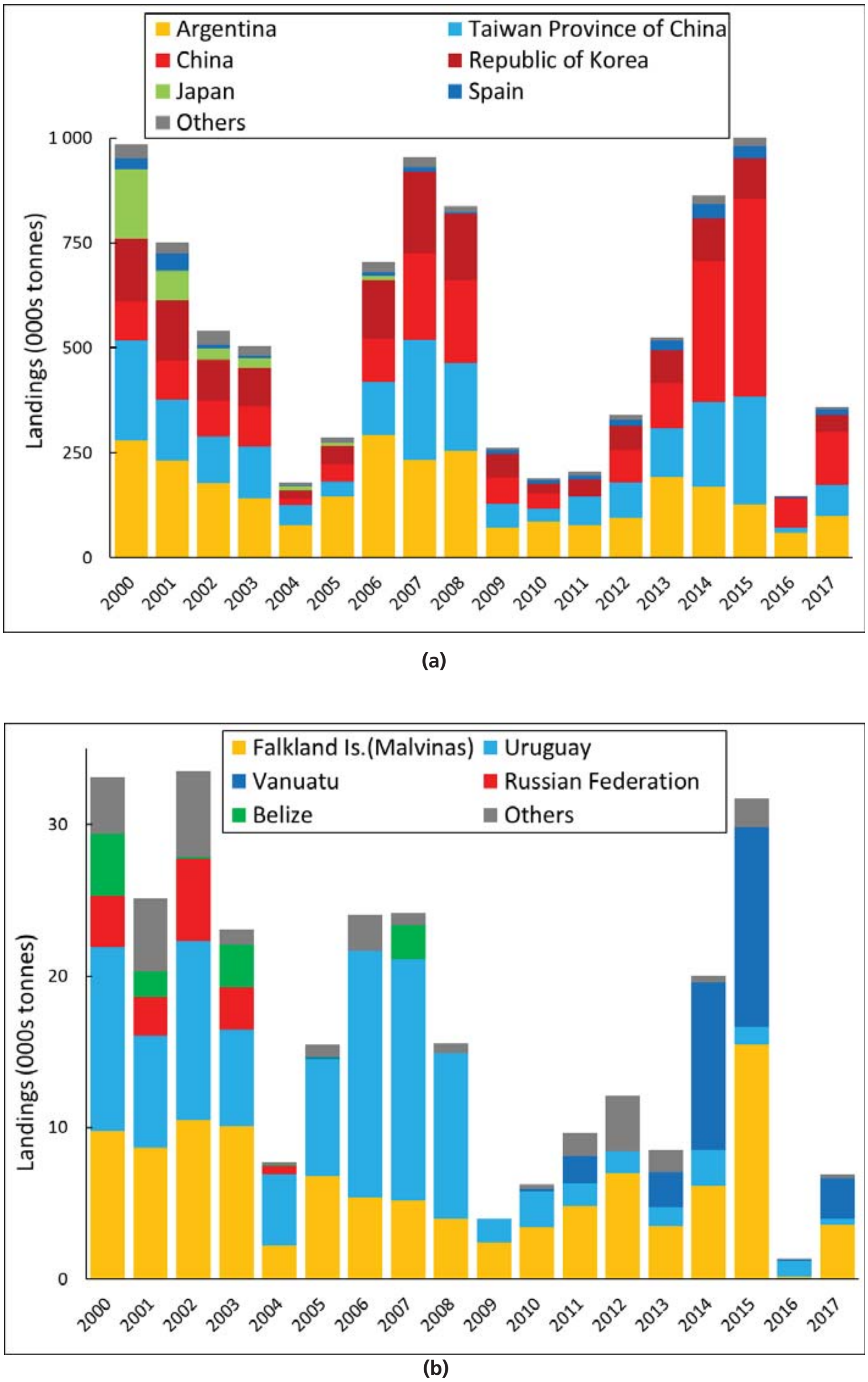
The fisheries for Argentinian shortfin squid are mainly undertaken with midwater trawls and jigging, and hence pelagic in nature. However, in the past some fishing with bottom trawls has occurred. Argentine trawlers have taken squid as bycatch since the 1930s, though large catches were not reported until the former USSR fished for hake in the newly established Argentine EEZ in 1967, when as much as 15 000 tonnes were taken. For a decade, catches then reverted to the bycatches of local trawlers. A targeted fishery began on the Patagonian Shelf in 1978, taking 73 000 tonnes that year, of which 59 000 tonnes was taken by Argentine vessels (Csirke, 1987; Brunetti, 1990; Arkhipkin *et al*., 2015a). Catches increased and a large-scale international fishery commenced in 1980, with as many as 90 large factory trawlers and 120 jigging vessels under the flags of 14 states. Catches reached of 190 000 tonnes in 1982 and 230 000 tonnes in 1985. The fishery operated across the shelf and slope in the high seas area between 41–47° S at 200–1 000 m depth in autumn and winter, with the major fishery remaining within the EEZs. The character of the fishery changed in the 1990s with the break-up of the former USSR leading to a reduction in trawling activity. The overall regional catch of Argentine shortfin squid reached a peak of 1 200 000 tonnes in 1999, of which 36 percent was taken by jigging within the Argentine EEZ. Since 2000, some 22 countries have reported catches in the southwest Atlantic (Figure 9.4; FAO, 2019). Catches then fell to under 180 000 tonnes in 2004, recovered to 960 000 tonnes in 2007, but since

TABLE 9.3
Reported high seas catches (tonnes) in southwest Atlantic from bottom trawls and longlines in 2003–2014

Country	Year	Argentine hake	Argentine shortfin squid	Rock cod	Patagonian grenadier	Pink cusk eel	Southern blue whiting	Patagonian toothfish	Patagonian scallop	Other	Total catch	Source
Argentina	2009	113	239		243		0	5	61		730	INIDEP, pers. comm.
	2010	299	50		76		77	30	11		576	
	2011	4	74		0		0	2	16		102	
	2012	1	17		0		0	0	0		20	
	2013	53	1 188		83		0	1	< 1		1 340	
	2014	9	23[1]		18		1	< 1	26		78	
Estonia	2005											
	2006	700	499	127	73	22				48	1 469	Bensch, 2009: Table 3
Republic of Korea	2006							≤1 800				
Spain	2003	7 136	9 266	36	1 550	818				3 567	22 373	Bensch, 2009: Table 2
	2004	17 255	2 788	317	526	566				1 462	22 914	
	2005	21 403	11 111	1 275	2 709	1 193				4 880	42 571	
	2006	22 283	14 481	2 865	1 858	1 049				2 431	44 967	
	2014	19 000	14 000	24 000[2]	< 100					2 000	120 000	J.M. Portela, IEO, Vigo, personal communication
Uruguay	2004	39 613	3 072					53			43 368	Bensch, 2009: Table 4
	2005	41 181	4 894					669			46 744	
	2006	28 029	4 989					130			33 149	

[1] an additional 430 tonnes were caught by jigging.
[2] mainly longtail southern cod.

FIGURE 9.4
Landings of Argentine shortfin squid in the southwest Atlantic in 2000–2017 for FAO Major Fishing Area 47 (national waters and high seas) for: (a) main states, and (b) details of "others" category



Source: FAO, 2019.

declined again to around 200 000 tonnes (Arkhipkin *et al*., 2015a). The trawlers mainly fished with midwater trawls, with their footropes near the bottom and their headlines as much as 50 m above, though there was some bottom trawling. The night-time jig fishery, using artificial light, was entirely off-bottom (Chen *et al*., 2007a, 2007b; Arkhipkin *et al*., 2015a; Ivanovic *et al*., 2016).

FAO have received some replies to specific questionnaires regarding catches in the southwest Atlantic high seas; while incomplete, these are reported here (Table 9.3) and include: Argentine shortfin squid taken in the high seas by Estonia, Spain, and Uruguay during 2003–2006 (Bensch *et al.*, 2009), by Spain (2014), and by Argentina (2009–2014). Annual averages from these data amounted to 10 329 tonnes by Spain, 4 318 tonnes by Uruguay, 499 tonnes by Estonia (fishing in 2006 only), and 337 tonnes by Argentina. The Republic of Korea also reported fishing for squid in the southwest Atlantic high seas, both as a minor bycatch in their bottom trawl fishery targeting hake and as a major targeted jigging fishery. The high seas catches much lower than in national waters: for example, Argentina averaged 104 420 tonnes per year from its national waters during 2009–2014 (Figure 9.4).

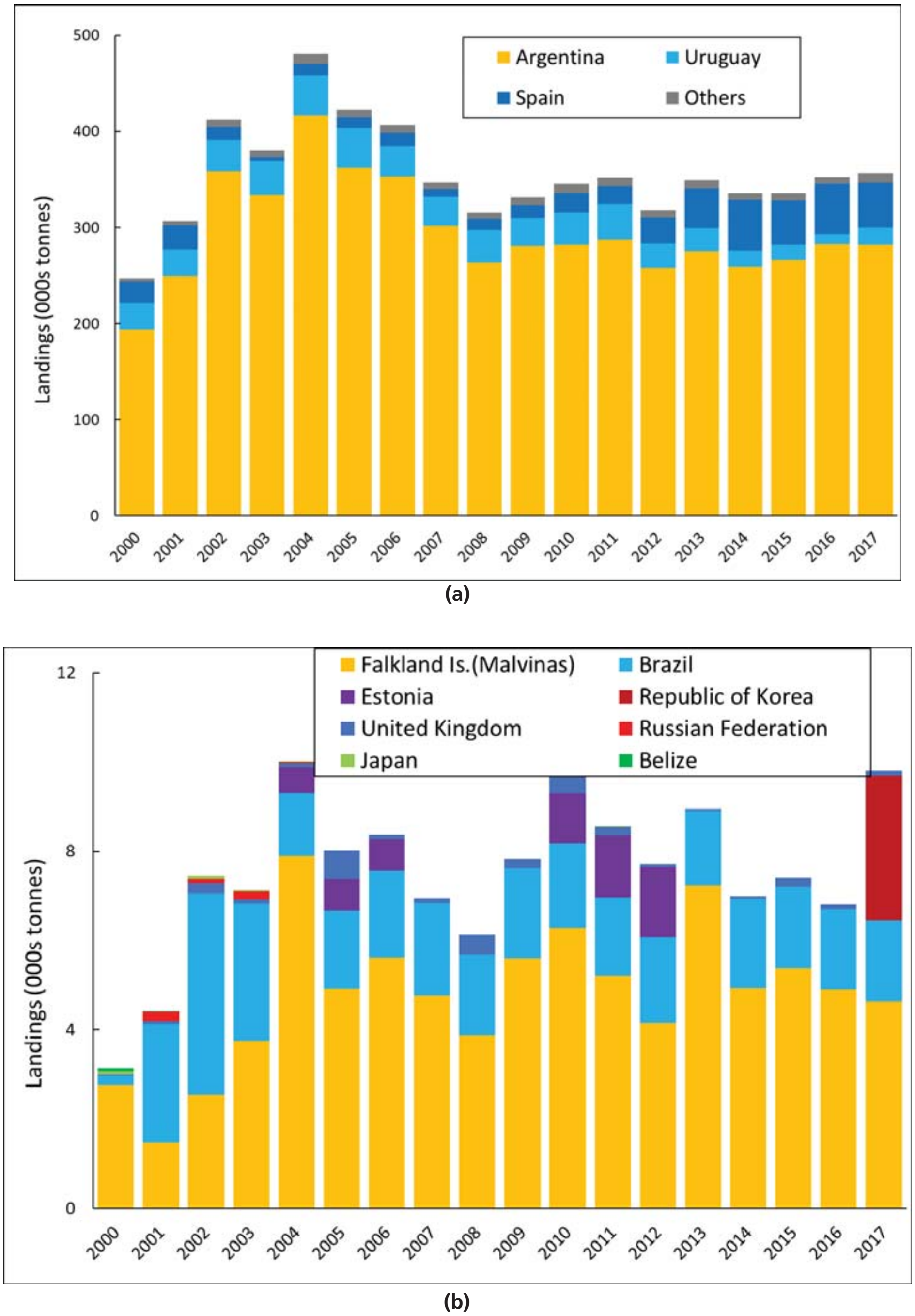
The second squid species in the region, Patagonian squid, is usually harvested by bottom trawl in continental-shelf waters. In 2016 the region-wide catch amounted to 52 269 tonnes. The directed fishery, which began in 1980, originally extended into the high seas but this is no longer the case (Csirke, 1987; Vasconcellos and Csirke, 2011; Arkhipkin *et al.*, 2015a). Finally, some seven-star flying squid are caught on the outer Patagonian Shelf, though only a few thousand tonnes per year (Vasconcellos and Csirke, 2011). It is unclear whether any are taken in the high seas.

Argentine hakes

Hakes have long been the most important demersal resource species of the southwest Atlantic: Argentina's commercially fishery started in the 1920s and was mainly confined to coastal waters within 200 km of the principal port, Mar del Plata (Portela *et al.*, 2002b). The Argentine trawler fleet and its hake catches grew during the 1960s, with some Uruguayan involvement also beginning then. The fishery continued to be focused in the north, off the Río de la Plata, where the catch was exclusively Argentine hake (Bezzi *et al.*, 1995; Portela, 2015). The former USSR fished for hake in the mid-1960s, taking 56 000 tonnes of hake in 1966 (Portela, 2015). Argentina responded by extending its jurisdiction out to 200 nautical miles from its coastlines (Jacobson and Weidner, 1989). The former USSR then fished under Argentine licenses in 1967, with 70 factory trawlers taking more than 500 000 tonnes. Alarmed by the high fishing effort and catches nearly three times those of its own fishermen, the Argentine government increased license fees for 1968 and demanded catch reporting, which ended the fishing interests of the former USSR in 1968 (Jacobson and Weidner, 1989; Irusta *et al.*, 2001; Vasconcellos and Csirke, 2011).

Fishing by vessels from coastal states continued to grow, reaching close to 170 000 tonnes in 1973 and 1974. From 1976, Argentine companies partnered with Spanish interests, which brought both factory-freezer trawlers and access to a large European market. The combined Argentine and Uruguayan catch peaked at 428 000 tonnes in 1979, when the total hake catch by all flag states reached 462 000 tonnes. The regional total peaked at 682 000 tonnes in 1996, almost all taken by Argentina, with Uruguay catching almost all of the rest. Catches remained around 300 000 tonnes annually until at least 2015 (Bezzi *et al.*, 1995; Irusta *et al.*, 2001; Vasconcellos and Csirke, 2011; Lorenzo and Defeo, 2015). With the exception of Spain, catches by non-coastal states have been small, with Japan and the Russian Federation reporting no catches since 2004 (Figure 9.5). The distant-water fleets increased in the early 1980s, especially by the former USSR in 1982–1989, together with Japan, Poland and Portugal in the mid-1980s (Csirke, 1987; Bensch *et al.*, 2009). The Spanish fleet eventually came to dominate, notably with their "la flotta de Malvinas", which focused almost entirely on waters that are now under national jurisdiction. Unfortunately, it is not possible to quantify the proportion of fishing by coastal states and distant-water fleets that occurred in the high seas.

FIGURE 9.5
Landings of Argentine hake in the southwest Atlantic in 2000–2017 for FAO Major Fishing Area 47 (national waters and high seas combined) for: (a) main states, and (b) details of "others" category"



Source: FAO, 2019.

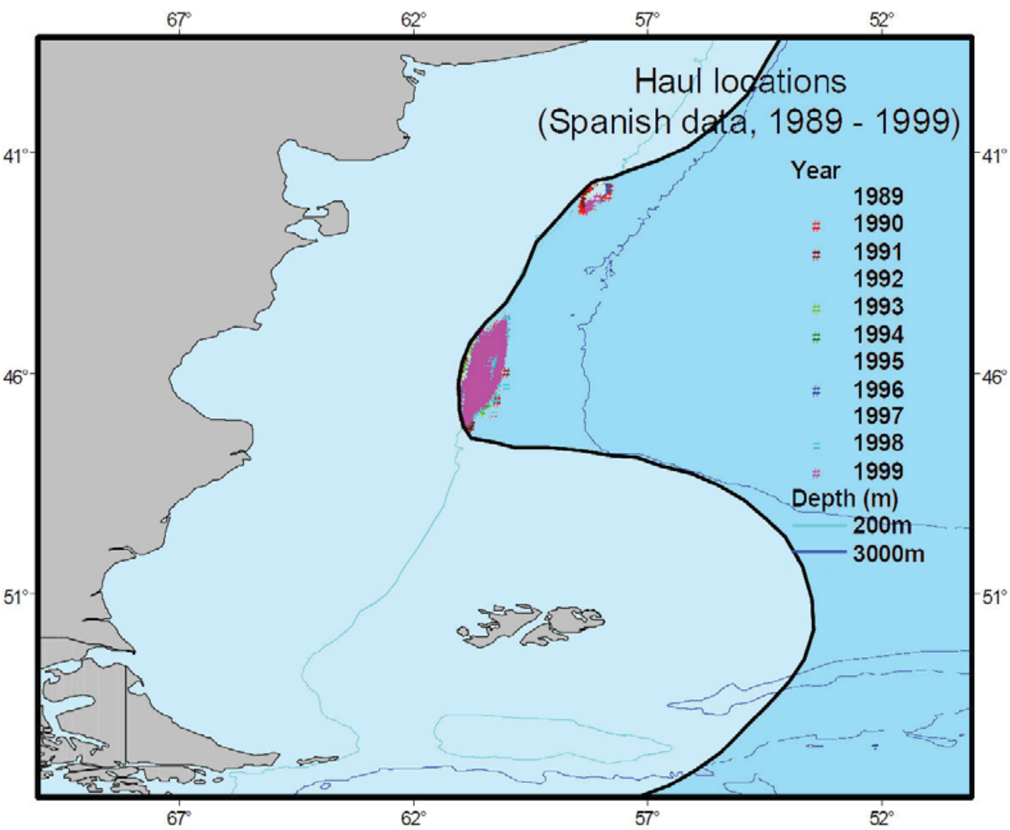
The catches of hake in the high seas are from a stock that straddles the 200-nautical-mile high seas boundary, though the proportion caught in the high seas is very small relative to that caught within national waters. However, the catch is still significant in terms of global high seas catches, and its management is important to safeguard the stock as a whole as well as other ecosystem considerations that need to be managed relating to impacts of fishing on dependent and associated species (EC, 2002, 2007).

A detailed study was undertaken on the Spanish fleet fishing on the Patagonian Shelf from 1988 to 1999, at three different locations where bottom trawling for Argentine hake was targeted in the high seas and waters around the Falkland Islands (Malvinas) (Figure 9.6; EC, 2002). Onboard observers recorded fisheries and biological information with the objective of undertaking a partial stock assessment for Argentine hake and southern hake. The main bycatch species recorded were squid, Patagonian toothfish, pink cusk eel, Patagonian grenadier, tadpole codling and southern blue whiting.

Some more recent information is available from replies to questionnaires for this and the earlier review by Bensch *et al.* (2009). Bottom fishing in the high seas was reported by Spain, Estonia, Republic of Korea and Uruguay for at least some years during 2003–2006 (Table 9.3). Catches in the high seas by bottom trawl were made up of approximately 70 percent Argentine hake, with Uruguay and Spain taking annual averages of 36 000 tonnes and 17 000 tonnes respectively, while Estonia only reported 700 tonnes in 2006.

Argentina reported high seas catches for 2009–2014, whereas Spain estimated theirs for 2014 only. Argentine catches were minimal at between 1–299 tonnes per year (compared to their annual catches from national waters of 258 000–281 900 tonnes), whereas the Spanish catch was estimated at 19 000 tonnes. Other fisheries are known to operate in the high seas of the southwest Atlantic, but there is no formal mechanism to report these as high seas catches.[2] An analysis of FAO statistics lists Belize (to 2001), Japan (to 2004), the Russian Federation (to 2004), Estonia (to 2012), Republic of Korea

FIGURE 9.6
Map of Spanish bottom trawling to target Argentine hake in the high seas of the southwest Atlantic in 1989–1999



Source: Map re-drawn from EC (2002) to remove haul locations outside of the high seas.

[2] Formal reporting to FAO does not separate out national and high seas catches.

(in 2017), the United Kingdom of Great Britain and Northern Ireland and Spain, together with coastal states, as having caught Argentine hake in the southwest Atlantic in the 2000s (Figure 9.5). Fishing by the first four countries appears to have ceased. China reports catches of large pelagic species and Argentine shortfin squid from the southwest Atlantic, but none for Argentine hake.

Other trawl fisheries for finfish on the outer Patagonian Shelf

It is difficult to know if there are other directed bottom trawl fisheries in the high seas of the southwest Atlantic. Many of the bycatch species are landed and some are even of high value. Spanish vessels record bycatches of squid, Patagonian toothfish, pink cusk eel, Patagonian grenadier, tadpole codling, pink cusk eel and southern blue whiting (Table 9.3; EC, 2002; Bensch *et al.*, 2009). Those which may form part of a more targeted fishery in the high seas are as follows.

From 1975 distant-water fleets took thousands of tonnes of notothens ("cod icefishes", family Nototheniidae), presumably mostly longtail southern cod but also including some Patagonian rockcod. The regional catch reached 9 000 tonnes in 1985, though most was likely bycatch in fisheries for other species (Csirke, 1987; Portela, 2015). As late as 2002 it was normal practice for the Spanish fleet to discard all notothens while targeting hake and squid (Portela *et al.*, 2002a, 2002b). However, the increase in biomass of longtail southern cod led to a new focus on the species from 2003. Although catches have since declined from the peak years, they exceeded 36 400 tonnes in 2014. They dropped to a little over 14 400 tonnes in 2016, nearly 90 percent of which was caught by European vessels and most taken in the high seas.

Directed fishing for pink cusk eel began in the late 1980s and peaked at 35 000 tonnes in 1990; it is now around a fifth of that amount, and likely all within national waters. Catches by distant-water (primarily Spanish) fleets increased, peaked in 2014 at 5 314 tonnes, and dropped a little to 3 394 tonnes in 2016 (FAO, 2019), and some of which is likely to have been taken in the high seas.

Longlining for Patagonian toothfish

Patagonian toothfish are primarily a sub-Antarctic species and taken in deep, directed longline fisheries along the continental slopes off both coasts of South America (Collins *et al.*, 2010; Martínez and Wöhler, 2016). They are taken as bycatch in the bottom trawl fisheries, which operates primarily at lesser depths and tends to take smaller, younger individuals. Initially a bycatch fishery of only a few hundred tonnes per year existed in the early 1980s (Csirke, 1987), after which the resource was targeted, as southwest Atlantic catches increased to 5 000 tonnes in 1993, almost all taken by Argentine vessels and mostly by trawlers. Longlining expanded rapidly and catches jumped to 17 000 tonnes in 1994, peaking at over 20 000 tonnes the following year, mostly taken by Argentine vessels deploying longlines. Catches then declined gradually to 5 000 tonnes in 2005 (Wöhler *et al.*, 2005; Gorini *et al.*, 2007, 2015; Vasconcellos and Csirke, 2011). They recovered only a little over the following decade. Meanwhile, a longline fleet from the Republic of Korea, comprised of between five and nine vessels in each year in the 2003–2006 period (Bensch *et al.*, 2009), had begun fishing in the southwest Atlantic in 1997 and contributed about 700–1 900 tonnes to the overall regional catch each year thereafter. Almost all of the remainder was taken by Argentine vessels, including some high seas fishing under the Argentine flag where the Patagonian shelf and slope extend beyond the 200-nautical-mile limit.

Patagonian scallop fishery

The sedentary Patagonian scallop resource straddles the EEZ/high seas boundary. The scallops are distributed under the shelf break front, where the Falklands (Malvinas) Current and the waters of the Patagonian shelf meet. In the south, the scallop beds lie on the outer shelf, extending into the high seas (Lasta and Bremec, 1998; Mauna *et al*., 2008, 2010).

Small catches of a few hundred tonnes of Patagonian scallops have been taken by Argentina in the southwest Atlantic since at least the 1950s. However, the intensive directed fishery began around 1995–1996, using specialized factory trawlers which fish with otter trawls, not dredges (Lasta and Bremec, 1998). Catches by Argentina suddenly increased to 12 640 tonnes in 1995 and peaked at 80 810 tonnes in 2009, though they are currently at about half that amount. Uruguay also reported catches from 2000–2006 (FAO, 2019). The vast majority of the above catches are almost certainly within national waters.

However, it is noteworthy that the Patagonian scallop fishery continues to straddle that boundary even though annual catches only amount to a few tens of tonnes. A fleet of four factory trawlers (45–60 m length) is operated by two companies. A catch of 26 tonnes was reported to be caught in the high seas in 2014.

Northern warm water fisheries

Vessels from the former USSR explored the Trinidade–Martim Vaz seamounts in 1982, taking mostly pelagic species but also some demersal wreckfish and lutjanid snappers. They then fished the Rio Grande Rise during 1982 and 1984, taking 300 tonnes of alfonsino. Trawlers returned to the Rise in 2000 and by 2002 had taken a further 1 200 tonnes, almost all of which was alfonsino (Clark *et al*., 2007). No information on later high seas seamount fishing in the region is available.

Effort

There is very little information on fishing effort in the high seas. Bensch *et al*. (2009) gave some information for 2003–2006. Spain operated 22–27 bottom trawlers during 2003–2006, and Estonia just one trawler in 2005 and 2006, for 81 and 59 days respectively. The Republic of Korea operated 16 trawlers in 2006, though it is not known whether they were fishing with bottom or deep midwater trawls. Effort and gear were not reported by Uruguay. More recently, Argentina has reported its high seas fishing effort for 2009–2014 for freezer trawlers, longliners, and jiggers (Table 9.4). Effort varies tremendously and presumably relates to opportunistic behaviour when their large fleet sees fishing opportunities outside of their rich national waters.

TABLE 9.4
Argentine high seas catches (tonnes) by vessel type in 2009–2014

Vessel	2009	2010	2011	2012	2013	2014
Freezer trawlers	420	436	41	0	1 268	64
Freezer longliners	4	30	2	0	< 1	0
Freezer jiggers	211	39	57	17	35	430

Source: INIDEP, personal communication.

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10. Mediterranean Sea

FAO Major Fishing Area 37

SUMMARY

The Mediterranean is made up of a series of deep basins mostly exceeding 3 000 m in depth, and narrow continental shelves around much of the coastline. This chapter confines itself to fisheries on those species that occur mainly below 400 m depth. The fisheries in the Mediterranean are dominated by smaller vessels that stay relatively close to the coast, but owing to the particular topography these can still be bottom fishing in deep waters. Many of the countries also have fleets of larger vessels capable of trawling down to several hundred metres. It is very difficult to fit the Mediterranean into the context of the other areas considered in this review, where high seas fisheries are typically distinct from the smaller inshore fisheries. In addition, the collection and reporting of catch statistics for many of the fleets is less complete than for many other regions, and it is certainly not separated in a manner that allows us to determine a distinct deepwater catch.

European hake is the only finfish to be targeted regularly and predominately deeper than 400 m, though catches of other commercial fish species occur as well. Two species of deepwater red shrimp are caught almost exclusively below 400 m: the blue and red shrimp and the giant red shrimp. The deepwater rose shrimp is fished at shallower depths, though a proportion will be below 400 m. There is also considerable reporting at higher taxonomic levels and about half of the shrimp catches are reported in this way. Many of these are likely to be deepwater red shrimps. An estimate of the catches of deepwater species in 2016 is around 20 000 tonnes of finfish, mostly European hake, and about 25 000 tonnes of shrimp, mostly deepwater rose shrimp and blue and red shrimp. A further catch of unidentified Natantian decapod shrimp and other shrimp species amounts to an additional 12 290 tonnes, but much of this and some of the above hake catches are likely to come from shallower waters (Table 10.1).

TABLE 10.1
Deepwater bottom fisheries catch (tonnes) in the Mediterranean in 2016

Gear	Principal grounds	Principal flag states	Target species	2016 catch
Bottom trawl, Longlines	Widely distributed at 100–c.700 m	Italy, Spain, Greece, Tunisia	European hake	19 736
Bottom trawl	Balearic area at 400–800 m	Algeria, Spain, Italy	blue and red shrimp	2 738
Bottom trawl	Widely distributed at 300–500 m	Italy, Tunisia, Algeria	deep-water rose shrimp	19 847
Bottom trawl	Sardinia area at 400–700 m	Italy	giant red shrimp	2 631
Bottom trawl	Widely distributed at 50–700 m	Egypt, Italy, Turkey, Greece	other "red" shrimp and unidentified shrimp	12 290
Total				57 242

Source: GFCM, 2018a, 2018b.

SCOPE OF THIS CHAPTER

This review is concerned with fisheries in the international waters of the high seas, which for the main oceans focuses on waters outside of national jurisdictions and more than 200 nautical miles from land. The situation is less clear in the Mediterranean. In the previous review, Bensch *et al.* (2009) limited the scope of the Mediterranean chapter to the bottom fisheries operating primarily below 400 m depth; the same approach is adopted here. The primary focus is therefore on trawl fisheries for deep-living shrimps and for various fisheries on European hake, although an overview of other fisheries that operate extensively below 400 m depth is included. The catches provided in this chapter are mainly for the stock over its entire depth range, as it is not possibly nor particularly useful to arbitrarily split the catches by depth. Blue and red shrimp, giant red shrimp and deepwater rose shrimp are fished mainly below 400 m, though European hake can be fished at 100 m depth or less and the shallow water catch is substantial.

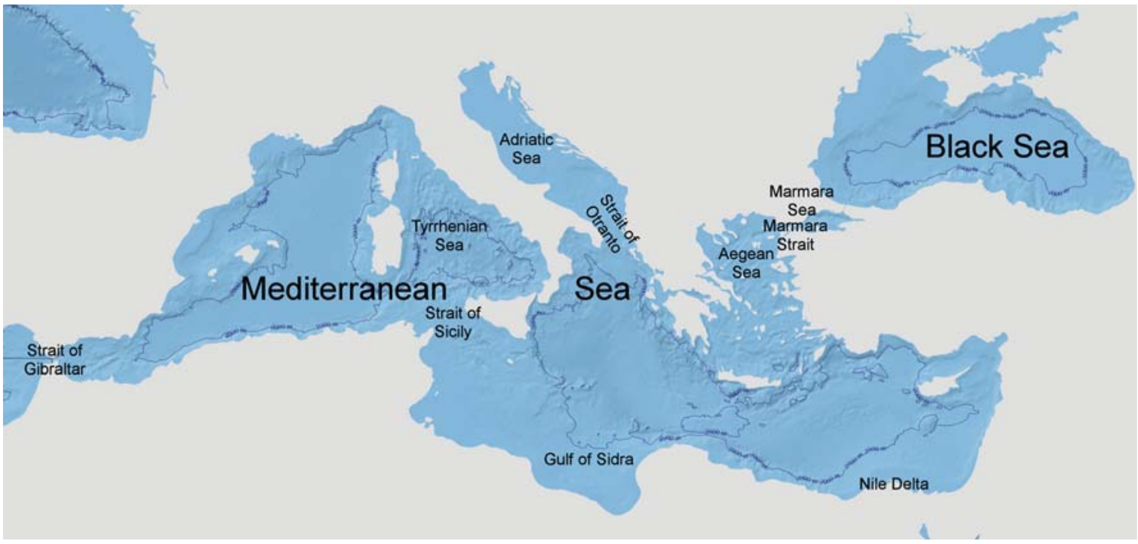
GEOGRAPHIC DESCRIPTION

The Mediterranean is the smallest region recognized by this review (Figure 10.1). It comprises of a series of deep basins, mostly exceeding 3 000 m depth, and continental shelves that vary greatly in width. The region's only natural connection with outside waters is the Strait of Gibraltar: 14 km wide, with a sill depth of about 300 m. A similar, though less extreme, restriction in the Strait of Sicily divides the deep basins of the western and central Mediterranean. Since 1869, the Suez Canal has provided a connection between the eastern basin and the richer ecosystems of the Red Sea, through which various invasive species have passed – the "Lessepsian migrants". While of concern shallower depths closer to the surface, these do not appear to have had any effect on the deep ecosystems of the Mediterranean. Due to the geographic features described above, the Mediterranean is considered the largest semi-enclosed sea in the world, and water interchange through the Strait of Gibraltar and through the Suez Canal, as well as water interchange with the Black Sea through the Marmara straits, together with internal water dynamics inside the Mediterranean water, drive oceanographic conditions in the Mediterranean.

Water circulation in the Mediterranean is driven by evaporation, especially in the extreme east, producing the warm, hypersaline Levantine Intermediate Water (LIW), which circulates around much of the Mediterranean at subsurface depths. The formation of deep water is complex and variable, inter-annually as well as in space, but everywhere involves winter cooling and mixing of the Intermediate Water. As a consequence, the deep basins are flooded with highly saline (> 38.4‰), warm (> 12°C) waters (Sardà *et al.*, 2004a; Tanhua *et al.*, 2013) – a marked divergence from those at similar depths in the rest of the World Ocean.

The main fishable areas at the deeper depths comparable to the other regions in this review are at 400–2 000 m (Table 10.2), though fishing with towed dredges and trawl nets has been prohibited deeper than 1 000 m in the Mediterranean since 2005 (Recommendation GFCM/29/2005/1). Such depths are found in the Mediterranean as a very narrow belt around the deeper basins, including the one in the southern Adriatic. There are broader extents at such depths in only a few areas: east of the Nile delta; in the Gulf of Sidra; in the Alboran Sea; around Ibiza (in the Balearic Islands) and off the adjacent coastline of Valencia; in the Strait of Otranto; in various parts of the Aegean and off Cyprus. The only extensive areas with depths of 400–1 000 m, however, lie among the shallows of the Strait of Sicily. While those potentially deep fishing grounds in the Mediterranean are limited, they total 356 000 km^2, which is more than the combined area of high sea shallower than 2 000 m in the northwest and the southwest Atlantic – two regions which dominate the worlds high sea bottom fisheries.

FIGURE 10.1
Map of the Mediterranean and Black Sea



2 000 m isobath (GEBCO).
Source: FAO VME Database, Mercator projection.

TABLE 10.2
Area statistics for the Mediterranean

Geographical area	Surface area (km²)
Total sea in the region	2 997 000
Area shallower than 400 m	676 000
Area shallower than 1 000 m	1 032 000
Area shallower than 2 000 m	1 480 000
Area deeper than 2 000 m	1 517 000

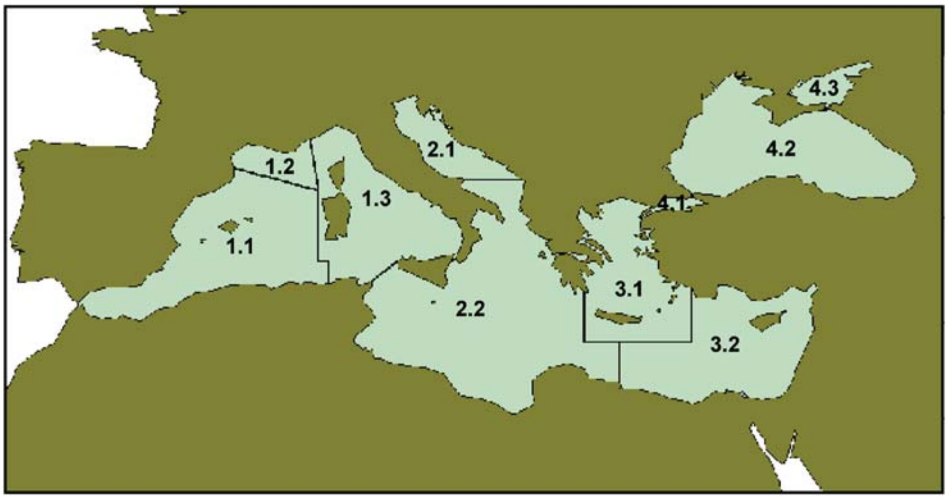
The Mediterranean and the Black Sea (FAO Major Fishing Area 37) are divided into western, central and eastern subareas, each of which is further subdivided into divisions (Figure 10.2). For the purposes of catch reporting to GFCM and FAO, Mediterranean and Black Sea countries use geographical subareas (GSAs) as the main management units (Figure 10.3).

ECOSYSTEMS AND RESOURCE SPECIES

The complex physical and chemical oceanography of the Mediterranean has recently been summarized by Tanhua *et al.* (2013). Importantly, evaporation exceeds precipitation, and the resulting difference in volume is made up primarily by a net inflow through the Strait of Gibraltar, though also through a small net supply from the Black Sea and a similar volume from river and groundwater discharges. Atlantic water from the Strait of Gibraltar forms the surface layer, circulating anticlockwise around the western basin with important eddies; some passes through the Strait of Sicily, then circulates around the eastern basin.

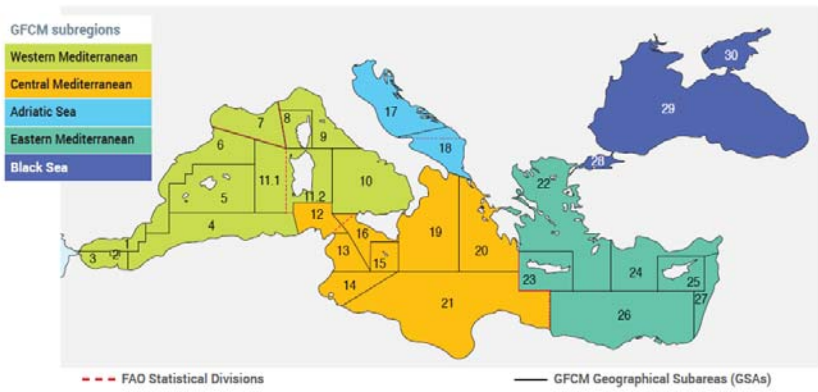
At the 400–1 000 m depths of the Mediterranean's deep fisheries, the eastern basin has temperatures around 14–15 °C and salinities of nearly 39‰, while the western basin has 13–14 °C and 38.5‰. Even the deepest parts of the Mediterranean have bottom temperatures of nearly 13 °C in the west and 14 °C in the east. Concentrations of plant nutrients in the surface layer are low everywhere but especially in the east, making the Mediterranean an oligotrophic system – indeed, some claim the eastern basin is among

FIGURE 10.2
Mediterranean and Black Sea showing subareas and divisions in FAO Major Fishing Area 37



Western Mediterranean subarea (37.1): Balearic (37.1.1), Gulf of Lions (37.1.2), Sardinia (37.1.3) divisions; Central Mediterranean subarea (37.2): Adriatic (37.2.1), Ionian (37.2.2) divisions; Eastern Mediterranean subarea (37.3): Aegean (37.3.1), Levant (37.3.2); Black Sea (37.4): Marmara Sea (37.4.1), Black Sea (37.4.2), Azov Sea (37.4.3) divisions. Note that the major fishing area prefix "37" has been omitted from the labels on the figure.
Source: redrawn from http://www.fao.org/gfcm/data/maps/gsas

FIGURE 10.3
GFCM area of application, subregions and geographical subareas



GFCM GSAs

01 - Northern Alboran Sea	07 - Gulf of Lion	13 - Gulf of Hammamet	19 - Western Ionian Sea	25 - Cyprus
02 - Alboran Island	08 - Corsica	14 - Gulf of Gabes	20 - Eastern Ionian Sea	26 - South Levant
03 - Southern Alboran Sea	09 - Ligurian Sea and Northern Tyrrhenian Sea	15 - Malta	21 - Southern Ionian Sea	27 - Eastern Levant Sea
04 - Algeria	10 - South and Central Tyrrhenian Sea	16 - South of Sicily	22 - Aegean Sea	28 - Marmara Sea
05 - Balearic Islands	11.1 - Sardinia (west) 11.2 - Sardinia (east)	17 - Northern Adriatic Sea	23 - Crete	29 - Black Sea
06 - Northern Spain	12 - Northern Tunisia	18 - Southern Adriatic Sea	24 - North Levant Sea	30 - Azov Sea

Source: GFCM website, http://www.fao.org/gfcm/about/area-of-application/en/

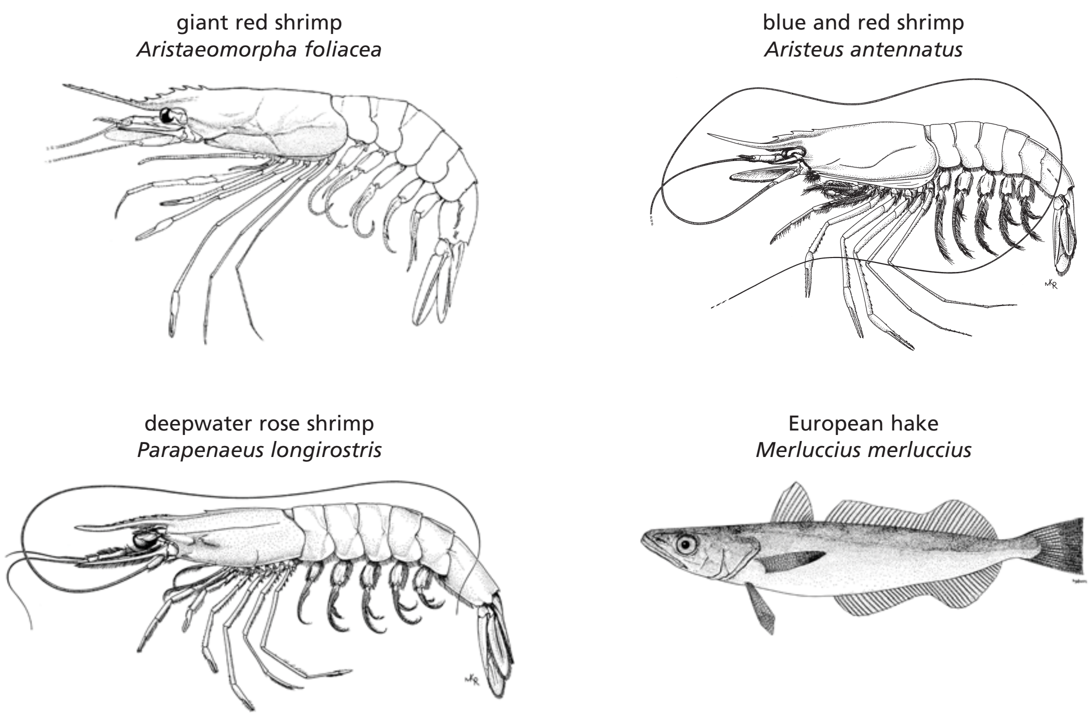
the most oligotrophic areas of the World Ocean. Despite the restrictions on water flow amongst the deep basins, water turnover is sufficient that oxygen concentrations are not limiting to marine life in any of the major basins (Tanhua *et al*., 2013).

Sardà *et al.* (2004a, 2009) have summarized knowledge of the Mediterranean's deepwater and seabed ecosystems. The principal feature is low productivity, not only because of the oligotrophic surface waters but also because the high temperatures at depth encourage mid-water consumption of such organic material as would otherwise sink to the seabed. The isolation of the basins, the high temperatures, low productivity and former periods of hypoxia led to a major loss in deep-living diversity following the Pleistocene, especially in the eastern basin. The biomass of the benthos is also low. However, the shorter-lived species are highly responsive to variations in supply of material from lesser depths, which can be seasonal but also episodic "cataclysmic" perturbations arising from unusual combinations of meteorological drivers at the surface.

The very different oceanographic processes in the Mediterranean, and the ecosystems which result from them, lead to biomass densities at depth that are at least an order of magnitude lower than those in the Atlantic. They also lead to a dominance of decapod shrimps, rather than fish, which is more pronounced further to the east (Cartes *et al*., 2004; Sardà *et al*., 2009).

As mentioned before, the principal deepwater fisheries are primarily supported by just three species: European hake, blue and red shrimp, and giant red shrimp (GFCM, 2016a, 2018a; Figure 10.4). This is in addition to Norway lobster, deepwater rose shrimp (primarily fished above 400 m depth) and "red" shrimp of the genus *Plesionika* (especially golden shrimp and soldier striped shrimp caught mainly below 400 m) though reported catches of these are usually under 100 tonnes per year. On the Strait of Sicily grounds, for example, deepwater rose shrimp is most abundant at 270–480 m, Norway lobster at 300–550 m, giant red shrimp at 550–650 m, blue and red shrimp at 600–700 m and various *Plesionika* sp. at 280–650 m (Spanò *et al*., 2013). Shrimp classification – particularly for the purposes of catch recording – is by species and by two higher taxonomical groups: Natantian decapods nei and Aristeid shrimps nei (Table 10.3; GFCM, 2018a). It is likely that there is significant confusion over the recording of these shrimp species.

FIGURE 10.4
Principal deepwater demersal resource species of the Mediterranean



Source: Food and Agriculture Organization of the United Nations, Original Scientific Illustrations Archive.

TABLE 10.3
Classification of Natantian[1] decapods caught in the deep waters of the Mediterranean

Classification	Blue and red shrimp	Giant red shrimp	Deepwater rose shrimp	"Red" shrimp: Golden shrimp and striped soldier shrimp
Order	Decapoda	Decapoda	Decapoda	Decapoda
Suborder	Dendrobranchiata	Dendrobranchiata	Dendrobranchiata	Pleocyemata
Family	Aristeidae	Aristeidae	Penaeidae	Pandalidae
Genus species	*Aristeus antennatus*	*Aristaeomorpha foliacea*	*Parapenaeus longirostris*	*Plesionika martia* and *Plesionika edwarsii*

[1] Natantia is an "unaccepted" suborder of decapod crustacea and include shrimps, prawns and boxer shrimps. It is still used as an official classification in the FAO STATLANT catch recording system (FAO, 2019b) (source for classification: WORMS, 2018).

The blue and red shrimp and the giant red shrimp are the most important commercial species of Aristeidae in the Mediterranean (Rinelli *et al.*, 2013). They inhabit muddy bottoms of the upper and middle slope, with the highest abundance of both species occurring between 600 and 800 m depth, where they often co-exist (Rinelli *et al.*, 2013). In the Mediterranean, the deepest occurrence of giant red shrimp is 1 100 m (Politou *et al.*, 2004) and 3 300 m for blue and red shrimp (Sarda *et al.*, 2004b). The two species have an antagonistic longitudinal gradient in distribution, with blue and red shrimp more abundant in the western Mediterranean and presenting decreasing densities eastwards, while the giant red shrimp is more abundant in the eastern Mediterranean with decreasing densities westwards (Politou *et al.*, 2004; Sarda *et al.*, 2004b; Rinelli *et al.*, 2013).

Blue and red shrimp is the most important deep resource in the western basin and in the western Ionian Sea, where it is mostly fished at 400–1 000 m depth between late winter and early summer, when the mature females form seasonal aggregations at fishable depths. The fishery continues later into the year, when it takes a mixture of sizes, ages and sexes. Blue and red shrimp have a maximum life expectancy of about five years. They appear able to sustain intensive fishing, perhaps because of their high turnover rate combined with the effective protection of the proportion of the population that lives below the fished depths: scattered at low density in these areas, males equal or exceed the abundance of females (Sardà *et al.*, 2003, 2004a, 2004b, 2009). Blue and red shrimp also occur in the eastern basin and the Strait of Sicily but the principal deep resource there is the giant red shrimp (Sardà *et al.*, 2004a, 2009). They are particularly abundant at depths of 600–800 m. Males and females appear to live to three and six years of age, respectively. Comparing the biological characteristics of the two species, including maximum depth, vertical distribution, recruitment depth and size at maturity, Politou *et al.* (2004) suggested that giant red shrimp is more vulnerable to overfishing than blue and red shrimp.

Various populations of European hake form a principal groundfish resource throughout the Mediterranean. They are isolated from the populations in the Atlantic and partially separated between the western and eastern basins. In the west, they are found from near shore to almost 1 000 m depth but are unusual below 500 m (Oliver and Massutí, 1995).

MANAGEMENT OF HIGH SEA BOTTOM FISHERIES

General Fisheries Commission for the Mediterranean (GFCM)

The General Fisheries Commission for the Mediterranean (GFCM) was established in 1949, pursuant to Article XIV of the FAO Constitution through an Agreement, which entered into force in 1952. The Agreement was amended in 1963, 1976, 1997 and 2014, the third of which changed the "Council" into a "Commission", while the fourth aimed, *inter alia*, to enhance sub-regional cooperation, ensure Member States' compliance with binding recommendations and long-term sustainability of ecosystems, fisheries and aquaculture. The main objective of GFCM is to promote the sustainable use, development, conservation, rational management and best utilization of living marine resources, as well as the sustainable development of aquaculture. The commission's responsibilities not only include keeping the fisheries and the living resources of the region under review, but also considering the economic and social aspects of the fishing industry, while formulating and recommending appropriate management measures, encouraging and coordinating research, promoting programmes for marine and brackish water aquaculture, and the assembly and publication of information.

The GFCM area of application encompasses all marine waters of the Mediterranean and the Black Sea. It therefore includes, among other areas, the Adriatic and Aegean seas, as well as the Sea of Marmara. For statistical purposes, the area of application has been subdivided into geographical subareas (GSAs; Figure 10.3). The commission's mandate covers all fisheries except those for large pelagic species.

GFCM is made up of 24 contracting parties, comprising 22 coastal states, Japan (as a distant-water fishing nation) and the EU. Georgia and Ukraine became cooperating non-contracting parties in 2015, followed by Bosnia and Herzegovina in 2016, the Republic of Moldova in 2017, and Jordan in 2018. GFCM operates in four official languages: Arabic, English, French and Spanish.

The commission meets annually, when it has the authority to adopt binding recommendations for fisheries conservation and management in its area of application – though members can opt out through objection procedures. GFCM implements its policies and activities during intersessional periods through its technical committees, their subcommittees and working groups, and with the assistance of its Secretariat. The committees comprise the Scientific Advisory Committee on Fisheries (SAC), the Scientific Advisory Committee on Aquaculture (CAQ), the Compliance Committee (CoC) and the Committee of Administration and Finance (CAF). The SAC, composed of individuals accredited by the contracting parties, is charged with providing independent advice on the technical and scientific bases for decisions concerning fisheries conservation and management, including their biological, social and economic aspects. Of particular relevance to this review, its subsidiary bodies include a Working Group on Stock Assessment of Demersal Species (WGSAD).

Since 2015, in order to further its objectives, GFCM has transitioned away from the former thematic approach, towards a subregional approach. Subregional committees have been established for the western Mediterranean, central Mediterranean, Adriatic Sea and eastern Mediterranean, in addition to the Working Group on the Black Sea established in 2012.

More recently, GFCM adopted a 2017–2020 strategy to ensure the sustainability of fisheries, which is intended to reverse an "alarming trend in the status of commercially exploited stocks" (Resolution GFCM/40/2016/2).

The commission has a suite of management measures also applicable to deep-sea bottom fishing, which are adopted through recommendations, resolutions and other decisions (Table 10.4; GFCM, 2017a).

With respect to specific recommendations addressing deep-sea fisheries, in 2005 Recommendation GFCM/29/2005/118 prohibited the use of towed dredges and trawl nets at depths greater than 1 000 m. The preamble to this recommendation notes that it is a precautionary measure mainly for the protection of fish stocks and to halt the expansion of fisheries into deeper waters when the stock status is unknown. In 2004, the SAC also made reference to the protection of vulnerable habitats, issuing advice to:

> *refrain expanding deep-water fishing operations beyond the limit of 1 000 m, in view of scientific considerations on the presence both of unmapped sensitive habitats (deep-water coral banks, sea vents, sea mounts, etc.), and of the fragile nature of deep-water fish assemblages as well as the presence of juveniles of different crustacean species at such depths.*
>
> **(GFCM, 2004, paragraph 80)**

This precautionary decision addresses both the management of deep-sea bottom fisheries and the protection of deep-sea benthic ecosystems. The area below 1 000 m covers a little over 1 700 000 km^2 (about 59 percent of the Mediterranean; c.f. Table 10.2).

More recently, specific recommendations on deepwater fishing were adopted for demersal fisheries of the Strait of Sicily and for deep-sea red shrimp fisheries in the central and eastern Mediterranean. In 2015, minimum standards were set for bottom trawling fisheries of demersal stocks in the Strait of Sicily (Recommendation GFCM/39/2015/2) and in 2016 a multi-annual management plan was established (Recommendation GFCM/40/2016/4, later repealed by Recommendation GFCM/42/2018/5) with the following objectives:

- to apply the precautionary approach;
- to bring exploitation rates of European hake and deepwater rose shrimp to levels consistent with maximum sustainable yield by 2020;
- to protect nursery areas;
- to reduce discarding;
- to adjust fishing capacity to match the reduced fishing mortality; and
- to achieve economic viability without overexploiting the resources.

Specific measures include:

- minimum sizes for European hake (20 cm total length; later extended region-wide) and deepwater rose shrimp (20 mm carapace length);
- special authorization requirements for vessels engaged in bottom fishing in the Strait;
- a VMS requirement;
- the establishment of three Fisheries Restricted Areas (FRA) to protect nursery grounds from trawling year-round; and
- a three-month seasonal closure of waters between the coast and the 200 m contour in the Gulf of Gabès.

The management plan also sets target fishing mortality rates for deepwater rose shrimp and European hake.

In 2018, two recommendations were adopted with a view to establishing multi-annual deepwater management plans for sustainable trawl fisheries targeting giant red shrimp and blue and red shrimp in the central (GSAs 19, 20 and 21; Recommendation GFCM/42/2018/4) and eastern Mediterranean (GSAs 24, 25, 26 and 27; Recommendation GFCM/42/2018/3). The objective of these two recommendations, virtually identical in their content, is to maintain fishing mortality for giant red shrimp and blue and red shrimp within agreed precautionary reference points and thus achieve/maintain fishing mortality at MSY. The recommendations are consistent with the precautionary approach, establishing transitional measures to be applied until the adoption of permanent measures, envisaged for 2020. During this transitional phase it is expected that the status of the two stocks will be regularly assessed and, if not possible, that fishing fleet capacity or fishing effort be maintained at the authorized levels exerted during the 2014–2017 period. Those contracting parties and cooperating non-contracting parties (CPCs) with developed fisheries are expected to provide lists of authorized vessels with an indication of their historical fishing effort. Among other things, they are also obliged to have VMS on board (or any other geopositioning system, if greater than 10 m length overall) and provide detailed reports on their fishing activities (operating days, operating area, total catch, discards), in order to enable the creation of maps of fishing grounds using VMS data by the end of 2020. CPCs with no fishery are not permitted to submit fleet development plans to the GFCM for consideration.

In addition to these decisions, in 2018 the commission endorsed specific protocols for the protection of vulnerable marine ecosystems (VMEs) in the GFCM area of application. These protocols include: a definition of Mediterranean deep-sea fisheries, a VME encounter reporting protocol (and associated list of Mediterranean

TABLE 10.4
Decisions adopted by GFCM relevant to deepwater bottom fisheries

Year	Decision	Summary
Gear restrictions, size limits, effort restrictions		
2005 2009	REC.CM-GFCM/29/2005/1 REC.CM-GFCM/33/2009/2	A minimum mesh size for trawl net codends has been set at 40 mm square- or 50 mm diamond mesh
2006	REC.CM-GFCM/30/2006/1	Developing management of fishing effort in the bottom trawl fisheries for, among others, European hake, "red shrimp" and Norway lobster, in specified areas
2012	OTH-GFCM/36/2012/1	Guidelines for multi-annual management plans
2016	REC.CM-GFCM/40/2016/5	Minimum fish size for European hake has been set at 20 cm total length
Area-based measures		
2005	REC.CM-GFCM/29/2005/1	Prohibition of towed dredges and trawl nets below 1 000 m depth
2006–2017	REC.CM-GFCM/30/2006/3 REC.CM-GFCM/33/2009/1 REC.MCS-GFCM/40/2016/4 REC.CM-GFCM/41/2017/3	Fisheries restricted areas for protection of vulnerable ecosystems and fish stocks
2015	REC.CM-GFCM/39/2015/2	Specific measures were adopted for the demersal fisheries of the Strait of Sicily
2016	REC.CM-GFCM/40/2016/4	Strait of Sicily multi-annual management plan
2017	REC. CM-GFCM/41/2017/3	Fisheries restricted area in the Jabuka/Pomo Pit in the Adriatic Sea
Bycatch control		
2011–2013	REC.CM-GFCM/35/2011/5 REC.CM-GFCM/35/2011/4 REC.CM-GFCM/35/2011/3 REC.CM-GFCM/36/2012/2 REC.CM-GFCM/37/2013/2	Reduce the potential for impacts on monk seals, cetaceans, sea turtles, and seabirds
2012	REC.CM-GFCM/36/2012/3	Prevent shark finning, skinning or beheading, and capture of certain shark species
Data collection, monitoring and enforcement		
1995–2017	RES-GFCM/21/1995/2 REC.MSC--GFCM/35/2011/1 REC.DIR-GFCM/41/2017/6	Data reporting Logbook
2005 2017	RES-GFCM/29/2005/2 REC.MCS-GFCM/41/2017/8	Foundations for a control and enforcement scheme Joint inspections schemes for Strait of Sicily
2016	REC.MCS-GFCM/40/2016/1	Port state measures to combat IUU fishing
2009	REC.MCS-GFCM/33/2009/6 REC.DIR-GFCM/33/2009/5	Fleet register
2009	REC.MCS-GFCM/33/2009/7 RES-GFCM/38/2014/1	VMS
2009	REC.MCS-GFCM/33/2009/8	IUU vessels list
2011	REC.MCS-GFCM/35/2011/1	Logbooks
2013	REC.MCS-GFCM/34/2010/2 RES-GFCM/37/2013/2	Guidelines for fishing capacity controls
2013	OTH-GFCM/37/2013/1	Developing interim subregional measures
2014 2017	OTH-GFCM/38/2014/1 REC.MCS-GFCM/41/2017/7	Roadmap to Combat IUU fishing in the Mediterranean Regional plan of action for the fight against IUU fishing

Source: http://www.fao.org/gfcm/decisions/en/

VME Indicators), provisions for the Mapping of existing deep-sea fishing areas and an Exploratory deep-sea bottom fishing reporting protocol in the GFCM area of application. Nonetheless, at the time of writing, no formal decision (i.e. Resolution or Recommendation) has been taken by the commission (GFCM, 2019).

Other multilateral agencies

While GFCM is the sole regional fisheries management organization (RFMO) managing fisheries in the Mediterranean and the Black Sea, multiple other bodies have mandates relating to the marine environment in the region, a number of which have Memoranda of Understanding with GFCM (Álvarez *et al*., 2016). Of these, the Mediterranean Action Plan (MAP) is worthy of note, as the first Regional Seas Programme adopted, in 1975, under the umbrella of the UN Environment Programme. The MAP was originally focused on protecting coastal waters from primarily land-based pollution. It was followed the next year by the Convention for the Protection of the Mediterranean against Pollution (the "Barcelona Convention"). In 1995, 21 states and the European Union adopted both a new Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (also dubbed the "Barcelona Convention"), which came into force in 2004, in addition to a new Action Plan for the Protection of the Marine Environment and the Sustainable Development of the Coastal Areas of the Mediterranean (considered MAP Phase II). The Coordinating Unit for MAP serves as the secretariat for the Convention.

Beyond pollution prevention, MAP now covers the safeguarding of natural and cultural resources, the management of coastal areas and the integration of environment and development. The convention has an accompanying Specially Protected Areas and Biodiversity Protocol, under which there is a programme and "roadmap" for MPAs, a plan for conservation of sharks and rays, a plan for the conservation of habitats on seamounts and in submarine canyons, for the conservation of structure-forming benthos and for the conservation of chemosynthetic systems – all of which could impinge on management of deepwater bottom fisheries. Six Regional Activity Centres are responsible for the implementation of the respective parts of MAP, of which the Specially Protected Areas Regional Activity Centre (SPA/RAC) is concerned with the Specially Protected Areas and Biodiversity Protocol. In 2010 it generated a list of 13 priority open-sea areas for conservation, relevant to the impacts of fishing (de Juan and Lleonart, 2010a). Three of those correspond to GFCM Fisheries Restricted Areas and a fourth to the commission's closure of the seabed deeper than 1 000 m to all towed gears.

In 2012, GFCM and UNEP/MAP entered into a Memorandum of Understanding which commits the two organizations to cooperating in the advancement of their respective mandates, including in the arena of marine spatial planning. While the objectives of the two organizations have much in common – including the application of the ecosystem approach to fisheries – the memorandum also gives attention to mitigating cumulative risks arising from reduced access to space affected by multiple and conflicting uses.

DESCRIPTION OF BOTTOM FISHERIES

The Mediterranean, overall, lacks the large monospecific resources found in the outer oceans. Most fisheries in the region are mixed-species, often using small boats and fishing close to land. There are approximately 86 000 boats, with about 250 000 fishers working in the Mediterranean and Black Sea fisheries, but 84 percent of the boats belong to the "small-scale" sector and are under 12 m overall length (FAO, 2019a). There are about 6 200 trawlers (with 34 000 fishers), of which 2 219 are 12–24 m length overall; only 701 are longer than 24 m. Annual landings of wild-caught fish from the Mediterranean (excluding the Black Sea) increased until 1994, reaching

1 087 000 tonnes, but then declined irregularly to 850 000 tonnes (valued at about USD 2.4 billion at first sale) by 2016. Most of the catch comprised small pelagic species. However, the trawlers used in bottom fishing were responsible for 46 percent of landed value overall (GFCM, 2018a).

The deep fisheries are a minor subset, with various gears being worked from generally small boats taking a mixture of species, although larger trawlers are relatively more important than they are in shallower fishing. It is the presence of deep water close to the coast and the dense human populations of coastal, seafood-consuming communities that have made such deep fishing viable, even in the low-productivity Mediterranean. No comprehensive catalogue of the fisheries operating deeper than 400 m in the Mediterranean has been prepared, though it is clear that trawling for the two species of "red shrimp" predominates, while European hake is the principal target finfish.

During the 1930s, an existing shrimp trawl fishery, taking shallow-dwelling species in the Ligurian Sea expanded beyond the 400 m isobath and exploited both giant red shrimp and blue and red shrimp. Similar fishing emerged off the Catalan coast of Spain and around the Balearics in the 1940s, with fishing depths there reaching 700 m. During the 1980s, there was further expansion down to 1 000 m (Sardà *et al*., 2004a). Other deep shrimp fisheries emerged subsequently around the Mediterranean, as much by local development as by dissemination from the western basin. The deepwater red shrimp fishery in the eastern–central Mediterranean has been developing since the 1960s when the Italian fleet of Mazara del Vallo began fishing predominantly for giant red shrimp in the Strait of Sicily. The progressive decrease in the catch rate of this species in these traditional fishing grounds, and the absence of deep trawling in the eastern Mediterranean, has from the early 2000s driven some boats to fish around Crete and Cyprus, as well as off the Turkish coast (Garofalo *et al.*, 2007; Vitale *et al.*, 2013).

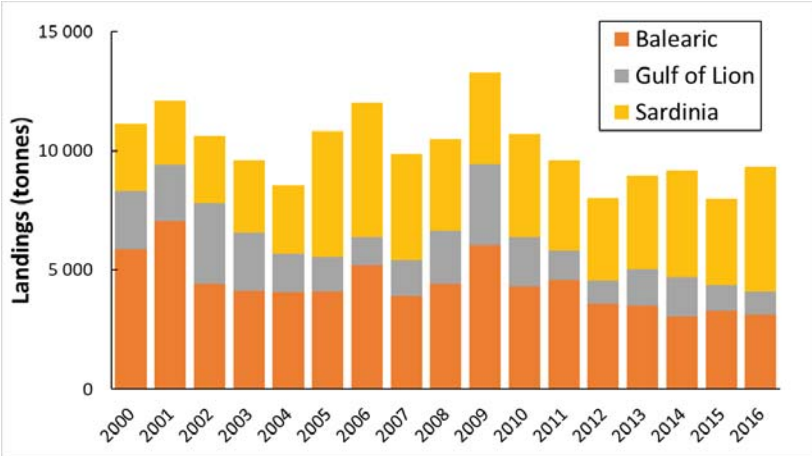
In contrast to the shrimp fisheries, the mixed-species trawl fisheries that took the majority of European hake was largely active in waters shallower than 300 m – where most of the European hake were juveniles – until the 1990s. Along with some deeper trawling, there were various longline fisheries that targeted adult European hake, including a directed fishery in the northern parts of the western basin. The mainlines were fitted with alternating weights and floats so that spans of the gear were off-bottom. Such longlines were set at depths as great as 700 m, particularly in the canyons of the Gulf of Lion and off the Spanish coast. There was also some gillnetting for European hake in the western basin and trammel netting in the east. Catches in the severely oligotrophic waters of the latter basin were very much lower than those in the west, and almost all of them came from the Aegean, where phytoplankton benefit from higher nutrient levels in the Black Sea outflow (Oliver and Massutí, 1995; Papaconstantinou and Stergiou, 1995).

Western Mediterranean

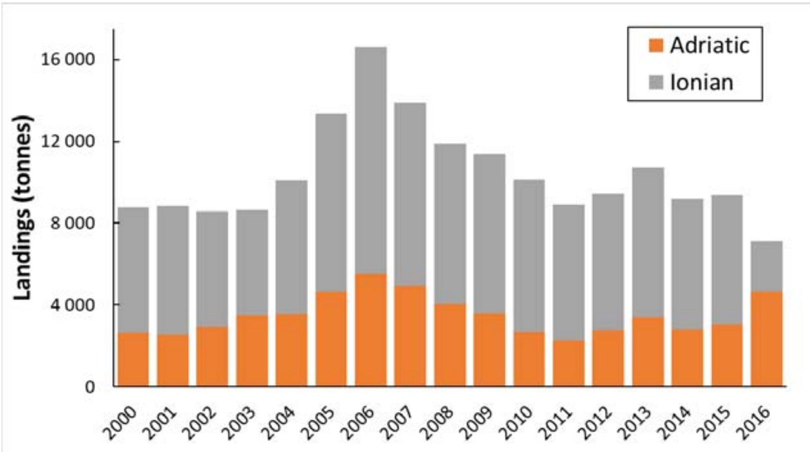
Overall, reported catches of European hake appear to be stable in the western Mediterranean, with slight increases around Sardinia being compensated by decreases in the Balearics, and an average for the subarea of 10 134 tonnes during the 2000–2016 period (Figure 10.5a). Percentages from the Balearic, Gulf of Lion, and Sardinia division were 43 percent, 18 percent and 38 percent respectively; the differences can largely be accounted for by the size of the division. It is not known what proportion comes from waters deeper than 400 m.

Shrimp catches are much harder to determine, primarily because they have mainly been reported either by species name or under one of the two shrimp groupings of Aristeidae and Natantia. The former group includes only the deepwater giant red shrimp and the blue and red shrimp, whereas the latter includes all shrimp. Catches from the

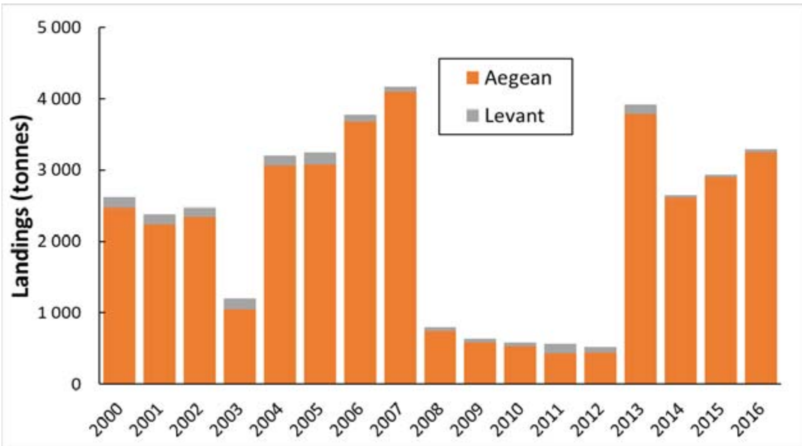
FIGURE 10.5
Reported catches of European hake in: (a) western, (b) central, and (c) eastern Mediterranean subareas, by FAO division in 2000–2016



(a)



(b)



(c)

Source: GFCM, 2018a.

Balearic and Gulf of Lion include high proportions of blue and red shrimp, whereas the Sardinia division is almost entirely made up of the shallow-dwelling deepwater rose shrimp. The total reported catches have remained reasonably stable, with occasional highs and lows. Overall average reported catches for the blue and red shrimp and the giant red shrimp are around 2 000 tonnes and 30 tonnes respectively, and these would all have come from below 400 m. Unidentified Natantian shrimp averaged 900 tonnes for the same 2000–2016 period, but it is not whether these are mainly deepwater rose shrimp and/or other species caught from shallower areas (Figure 10.6).

In the northern Alboran Sea (GSA 01), there is trawling for European hake on seamounts, at depths down to 800 m (de Juan and Lleonart, 2010b). In 2016, the European hake fishery was exploited by 110 small trawlers averaging 35 GRT (91 percent of landings), plus some longlines (3 percent of landings) and gillnets and trammel nets (6 percent of landings). In 2016, combined landings amounted to 185 tonnes, the lowest since the time series began in 2003, but landings increased to 288 tonnes in 2017 (GFCM, 2015, 2017b, 2018c). GSA 01 is also trawled for blue and red shrimp, with average landings of 136 tonnes per year for 2015–2017 (GFCM, 2018c).

The deepwater fishery around Alboran Island (GSA 02) for blue and red shrimp is targeted by the largest vessels of the deepwater trawl fleet operating on the middle slope, with trips lasting four to five days. The fishery is very weather-dependent with an average of 15 vessels in total and 47 tonnes landed annually during 2015–2017 (GFCM, 2018c).

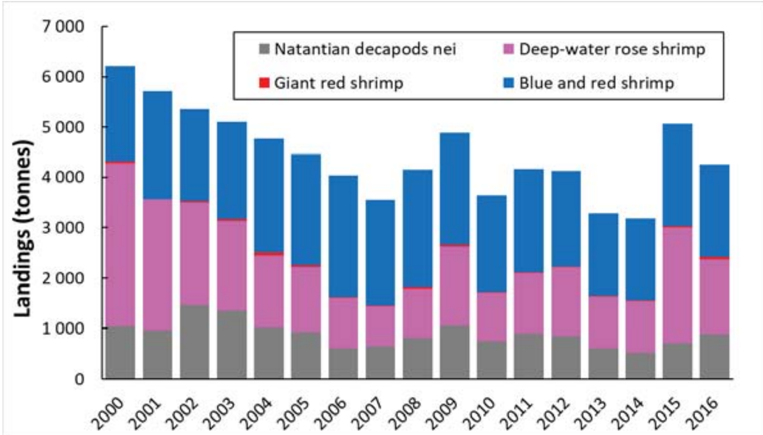
The finfish trawling fleet in the southern Alboran Sea (GSA 03) in 2016 comprised 72 vessels, targeting various species including European hake. The mean annual European hake production for 2015–2017 was 117 tonnes (GFCM, 2017b, 2018c). The Algerian shrimp fishery began working below 400 m on the continental slope in 1999, targeting blue and red shrimp, though the fishing had not exceeded 530 m depth by 2006. It took only a few tens of tonnes annually (Mouffok *et al*., 2008).

The trawl fishery off Algeria (GSA 04) is on the shallow shelf and slope at depths of 100–200 m and, though it catches European hake, is beyond the scope of this review. Small-scale fishers in this area also use gillnets and trammel nets.

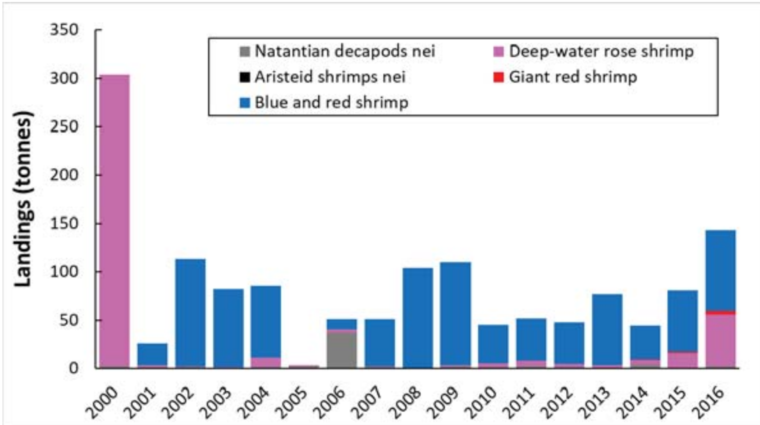
Deep trawling continues around the Balearics (GSA 05), where there are four recognized fisheries at shallow-shelf and deep-shelf depths, on the upper slope and the middle slope. European hake is the principal target of a mixed-species finfish fishery on the deep shelf (80–250 m). Annual European hake landings from the GSA vary between 50 tonnes and 190 tonnes, all taken by trawling (GFCM, 2018c). The upper-slope fishery operates at 350–600 m, targeting Norway lobster, with large European hake, megrim, anglerfish and blue whiting as important bycatch species. The mid-slope fishery (600–750 m) targets blue and red shrimp (GFCM, 2018c). The deep fishery works from late winter to early summer, targeting the schools of blue and red shrimp which form on the continental slope at that time of year (Sardà *et al*., 2004a).

The fishery targeting European hake off Spain (GSA 06) is one of the largest in the Mediterranean and prosecuted by trawlers (which take 91 percent of landings) and by small-scale fishers using longlines (6 percent of landings) and gillnets and trammel nets (3 percent of landings). There are some 1 000 boats taking part in this fishery, with landings of 1 810 tonnes of European hake in 2016 – a decline when set against the average of 3 004 tonnes for 2002–2016. In 2016, there were 437 trawlers that landed 1 719 tonnes of European hake (GFCM, 2017b, 2018c). However, much of this fishery is likely to be in shallower waters and really outside of the scope of this review. Approximately 200 trawlers work off the Spanish coast, north of the Alboran Sea (GSA 06). Some target deepwater rose shrimp, with annual landings

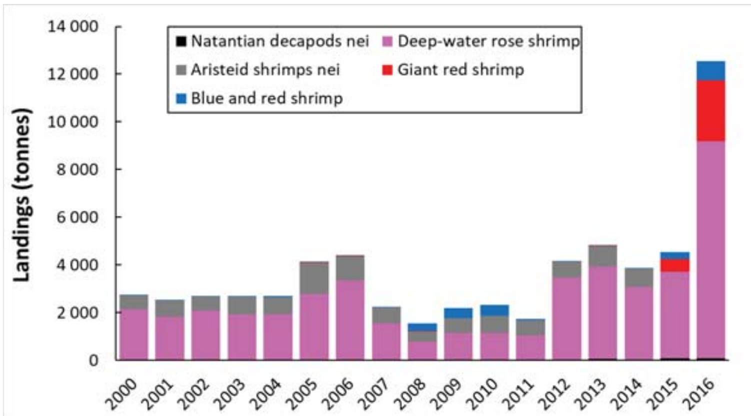
FIGURE 10.6
Reported catches of shrimp from the western Mediterranean in the FAO divisions: (a) Balearic, (b) Gulf of Lion, and (c) Sardinia in 2000–2016



(a)



(b)



(c)

Source: GFCM, 2018a.

of around 100–150 tonnes (GFCM, 2015, 2017b, 2018c). However, blue and red shrimp are the most valuable, comprising only 3 percent of Catalonian landings by volume but 21 percent by value, sometimes reaching prices of EUR 200/kg. Annual landings of this species are highly variable, driven by the cascades of dense water from the Gulf of Lion, but those taken by Catalonian trawlers have amounted to 500–700 tonnes annually in recent years (Gorelli *et al*., 2016).

The Gulf of Lion (GSA 07) is more productive at depth. A complex network of trawl, gillnet and longline fisheries by some 250 Spanish and French vessels work the continental slope, fishing mostly above 400 m depth but with some deeper effort – including fixed gears fished down to 1 200 m. The principal target is European hake but a variety of species is harvested, including deep-living forms such as monkfish, European conger, megrim, horned octopus and blue whiting. Annual European hake landings averaged 1 914 tonnes over 1998–2016, but were only 1 057 tonnes in 2016, of which 74 percent was taken by the French trawling fleet (de Juan and Lleonart, 2010a, 2010b; GFCM, 2017b). Catches of blue and red shrimp from this division are modest at 50–100 tonnes per year.

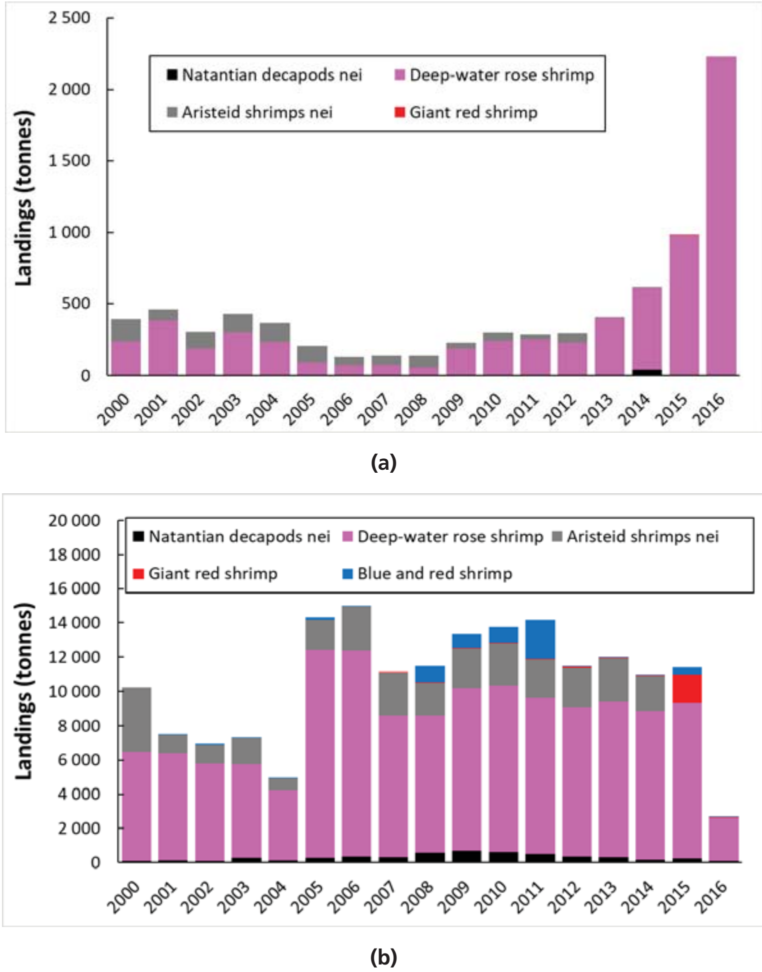
The deepwater shrimp resources in the Ligurian Sea and the northern Tyrrhenian Sea (GSA 09) declined in the late 1970s, after nearly half a century of exploitation. Blue and red shrimp soon recovered but by the end of the twentieth century the giant red shrimp, fished throughout its depth range, had not (Sardà *et al.* 2004a). Deepwater rose shrimp continue to be fished at lesser depths (150–350 m), as a component of a mixed-species trawl fishery that also targets European hake, horned octopus, Norway lobster and "red shrimp" down to 650 m – though catches also include a wide variety of other species that make a substantial contribution to overall landed value. European hake are also exploited by artisanal vessels using particularly gillnets that take almost half of the total catch (Sartor *et al*., 2003; GFCM, 2015, 2017b).

Central Mediterranean

Reported catches of European hake in the central Mediterranean during 2000–2016 peaked around 2006 and have declined by some 50 percent in the large Ionian division (Figure 10.5b), whereas catches in the Adriatic have been more stable. Average catches during this period were 6 400 tonnes and 3 500 tonnes respectively, though again it is not known how much of this was from shallower waters. Reported catches of the deepwater blue and red shrimp and giant red shrimp have been very low, only reaching significant levels in 2008–2011 and 2015, with catches of around 800–2 200 tonnes per year. Catches of unidentified shrimp of around 2 000 tonnes per year have been reported, but this could be any species from shallow to deep waters (Figure 10.7).

The largest of the deep fisheries are those in the Strait of Sicily (GSA 12, 13, 14, 15 & 16), where giant red shrimp are especially prominent. Indeed, early in this century, the greatest combined landings of "red shrimp" were made in Bizerte, Tunisia and Mazara, Sicily (Sardà *et al*., 2004a). Deepwater rose shrimp are also harvested in the area, mostly above 400 m depth but with some taken as deep as 600 m. The Italian fleet operating in the Strait comprises mostly small (under 12 m length), coastal trawlers making one- or two-day trips but also some "distant" trawlers of over 24 m length, which make trips of up to four weeks. Both fleets fish at varied depths, often on the same trip, exploiting deepwater rose shrimp, giant red shrimp, Norway lobster and European hake, as well as shallower-dwelling resources, changing target species as their relative availability permits. The Tunisian fleet mostly works off its northern coast (GSA 12), landing at Bizerte and Kelibia. There are also Maltese and Libyan fleets operating in the area (Sardà *et al*., 2004a). European hake is an important bycatch for the shrimp trawlers but also a target for longliners and gillnetters, with landings by all fleets averaging more than 3 000 tonnes annually for 2007–2016. Other species taken include rosefish, greater forkbeard and monkfish (GFCM, 2017b).

FIGURE 10.7
Reported catches of shrimp from the central Mediterranean in the FAO divisions: (a) Adriatic, and (b) Ionian in 2000–2016



Source: GFCM, 2018a.

The western Ionian Sea (GSA 19) is likewise fished for shrimp, Norway lobster and European hake by a fleet of more than 200 small Italian trawlers, alongside their fishing for other species at lesser depths. Both giant red shrimp and blue and red shrimp are important. There is also some small-scale longlining targeting European hake, rosefish, greater forkbeard and bluntnose sixgill shark, among other species (Sardà *et al.*, 2004a; GFCM, 2017b).

Greek trawling in the eastern Ionian Sea (GSA 20) does not usually extend below 500 m depth. Target species there include European hake, blue whiting, monkfish, blackspot (=red) seabream and others. There is some longlining at greater depths for European hake and wreckfish, while Italian trawlers work there at 400–800 m for "red shrimp", Norway lobster, European hake, blue whiting and others (Sardà *et al.*, 2004a).

Adriatic Sea

Most of the fishing in the Adriatic is necessarily shallower than 400 m but the European hake fishery there extends down to 800 m depth in the one deep basin (in GSA 18). Deepwater rose shrimp are taken in the same area at depths of 50–500 m, while Norway lobster is targeted at 50–400 m, particularly in the Jabuka/Pomo pit.

Bycatch includes horned octopus, monkfish and megrim. Most of the catch is taken by Italian and Croatian trawlers but there are also fleets from Albania and Montenegro, while some boats use longlines, gillnets or trammel nets (GFCM, 2017b).

Eastern Mediterranean

The eastern Mediterranean comprises of the Aegean and Levant divisions, though reported catches in the latter have been very low for both European hake and shrimp. Recent reported catches of European hake in the Aegean for 2000–2016 have been variable, ranging from around 500 tonnes to 3 500 tonnes, with both good years and poor years (Figure 10.5c). Catches of shrimp in both divisions have been in the order of 1 500–3 000 tonnes in the Aegean and 400–12 000 tonnes in the Levant, though they are almost only reported at the lowest taxonomic level, and those reported to species are mainly deepwater rose shrimp (Figure 10.8).

In the Aegean (GSA 22) Greek fishermen use longlines, gillnets and trammel nets to target European hake (at depths down to 700 m) but also blackspot (=red) seabream (fished on rocky banks at 200–600 m depth) and wreckfish (at 300–1 000 m, usually on steep slopes). The bottom trawl fishery shifts its activity between shallow and deep grounds. In the 1990s it rarely operated below 500 m while targeting Norway lobster, European hake, megrim, monkfish, deep-water rose shrimp and shrimps of the genus *Plesionika*. After 2000 the fishery took to working deeper, down to 800 m, in late spring, taking giant red shrimp, blue and red shrimp, rosefish and others. In the 1990s, a longline fishery for bluntnose sixgill shark operated in the Aegean, at depths of 600–1 500 m (Mytilineou and Machias, 2007). It is unclear whether it has persisted, but it was the deepest fishing in the Mediterranean and among the deepest anywhere.

Apart from some European hake fishing off the Levant (Bensch *et al.*, 2009), deep fisheries did not develop in the Levantine Sea (GSA 24, 25, 26 and 27) before the present decade (de Juan and Lleonart, 2010a). Shrimp trawling has since expanded into those waters, mainly by Italian and Egyptian fleets.

Landings of European hake from the Mediterranean, as reported to FAO, totalled 19 700 tonnes in 2016 – but much of that was caught above 400 m depth. The principal flag state involved was Italy, with reported landings of 8 700 tonnes. Greece, Tunisia, Spain and France also reported substantial landings, totalling 7 900 tonnes between them. The distribution of the European hake fisheries has been broadly consistent over the recent past, though overall regional landings have declined from a peak of over 52 000 tonnes in both 1994 and 1995, as Italian landings have declined from 38 000 tonnes.

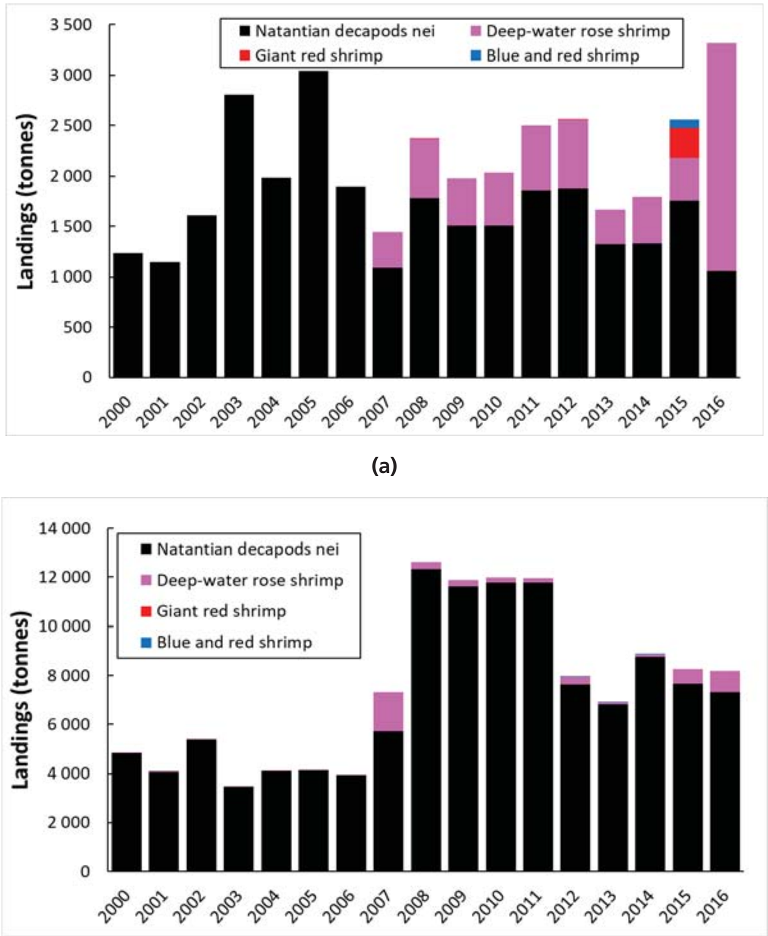
Equivalent information on the deep shrimp fisheries is not available, as much of the catch is reported to FAO merely as "Natantian decapods", without distinguishing between the deep and shallow species. Region-wide reported shrimp landings totalled 37 506 tonnes in 2016, of which 19 847 tonnes were identified as deepwater rose shrimp, with a further 12 290 tonnes as natantian decapods (much of it undoubtedly taken above 400 m depth). The majority of these were caught by Italian, Tunisian or Turkish trawlers. Only 2 738 tonnes of blue and red shrimp (most reported by Algeria and Spain) and 2 631 tonnes of giant red shrimp were identified to species level in the reports to FAO.

IMPACTS ON RESOURCES AND ECOSYSTEMS

Target resources

Current scientific advice on the status of deep resources is only available for European hake and three "red shrimp" species, and then only for certain GSA areas. The advice indicates that nearly all of the species stocks included in this review for which an assessment exists are suffering overexploitation from excessive

FIGURE 10.8
Reported catches of shrimp from the eastern Mediterranean in the FAO divisions: (a) Aegean, and (b) Levant in 2000–2016



(b)

Source: GFCM, 2018a.

fishing mortality. In general, there has been a general increase in fishing mortality for these species over the last five or so years. There is an urgent need to revert the trend and implement strategies to reduce fishing effort and fishing mortality (Table 10.5).

The recent scientific advice is not directly comparable with that summarized by Bensch *et al.* (2009), since assessment approaches and the reference points used in reporting the assessment results have both changed. However, widespread over-exploitation and a need to cut fishing effort was also evident in 2006.

In addition to the advice provided by the GFCM, Gorelli *et al.* (2016) have attempted an assessment of the blue and red shrimp resource exploited by Catalonian trawlers in GSA 06, though it required a significant – and questionable – reconstruction of missing or erroneous data. They found a sharp fall in their estimated catches and catch rates during the late 1960s, when fishing effort was still minimal, followed by a general slow decline in catch rates through a period of rapidly increasing catch and effort, until 2000. Catch rate appears to have increased since the severe 2005 and 2006 cascade events, as effort either stabilized or declined. It is unclear to what degree those trends in estimated catch rate since 1970 track changes in resource biomass. Cartes *et al.* (2011) reported that giant red shrimp

TABLE 10.5
Scientific advice on the status of the principal Mediterranean deep sea stocks (reported by species and by year)

European hake

Years	GSA	Stock status	Scientific advice
2016–2018	01 & 03	In overexploitation with low biomass	Reduce fishing mortality
2012–2015	01	In overexploitation with relatively intermediate-to-low biomass	Reduce fishing mortality
2018	04	In overexploitation with low biomass	Reduce fishing mortality
2012–2018	05	In overexploitation with high (2013), intermediate (2014–2016) to low (2017–2018) biomass	Reduce fishing mortality
2012–2018	06	In overexploitation with intermediate (2014–2016) to low (2017–2018) biomass	Reduce fishing mortality
2012–2018	07	In overexploitation with low (2012–2014, 2016–2018) to intermediate (2015) biomass	Reduce fishing mortality
2018	09–11	In overexploitation with low biomass	Reduce fishing mortality
2015–2017	09	In overexploitation with intermediate (2015) low (2016–2017) biomass	Reduce fishing mortality
2012–2018	12–16	In overexploitation with low (2012–2013, 2017–2018), intermediate (2016) to high (2014–2015) biomass	Reduce fishing mortality
2016–2018	17–18	In overexploitation with low biomass	Reduce fishing mortality
2012–2015	18	In overexploitation with intermediate (2013, 2015), to low (2014, 2016–2018) biomass	Reduce fishing mortality
2017	22	In overexploitation with low biomass	Reduce fishing mortality

Blue and red shrimp

Years	GSA	Stock status	Scientific advice
2014–2018	01	In overexploitation with intermediate biomass	Reduce fishing mortality
2018	02	In overexploitation with low biomass	Reduce fishing mortality
2012–2018	05	In overexploitation with low (2012–2013, 2015–2017) and high (2014) biomass	Reduce fishing mortality
2012–2018	06	In overexploitation with low (2016, 2018), intermediate (2012) and high (2014, 2017) biomass	Reduce fishing mortality
2016–2017	9	In overexploitation with low biomass	Reduce fishing mortality

Giant red shrimp

Years	GSA	Stock status	Scientific advice
2018	09–11	In overexploitation with low biomass	Reduce fishing mortality
2017–2016	09	In overexploitation with intermediate (2016) to low (2017) biomass	Reduce (2017) or no increase in (2016) fishing mortality
2014	19	In overexploitation with high biomass	Reduce fishing mortality

Deep-water rose shrimp

Years	GSA	Stock status	Scientific advice
2018	01	In overexploitation with high biomass	Reduce fishing mortality
2012, 2018	01 & 03–04	In overexploitation with low (2012) biomass	Reduce fishing mortality
2013, 2017–2018	05	In overexploitation with intermediate (2013, 2017) high (2018) biomass	Reduce fishing mortality
2012–2013, 2015, 2017–2018	06	In overexploitation with intermediate (2013, 2015) to high (2017–2018) biomass	Reduce fishing mortality
2018	09–11	In overexploitation with high biomass	Reduce fishing mortality
2015–2017	09	In overexploitation with high biomass (2017), or sustainably exploited (2015) with high biomass (2016)	Not to increase fishing mortality (2015–2017)
2012–2018	12–16	In overexploitation with low (2016), intermediate (2015, 2017) or high (2014, 2018) biomass	Reduce fishing mortality (2012–2018) and catches of undersized shrimps (2013, 2018)
2017	17–18	Sustainably exploited, with high biomass	Maintain the current level of fishing mortality
2012–2015	18	In overexploitation with intermediate (2015) to low (2014) biomass	Reduce fishing mortality
2016	19	In overexploitation with high biomass	Reduce fishing mortality

Source: GFCM, 2012, 2014a*, 2014b, 2105, 2016b, 2017b, 2018c; * recorded as 2013 in table.

disappeared from the Catalan basin in the 1960s, likely due to a synergistic effect between change in deepwater masses (i.e. increase in water temperature) which reduced the availability of the red shrimps' prey, and fishing pressure, thereby causing an overall drop in the species.

Other ecosystem components

Much has been written about the potential impacts of deep-sea fisheries in the Mediterranean on ecosystem components other than their target species (e.g. Tudela, 2004; de Juan and Lleonart, 2010a; Álvarez *et al*., 2016). However, these contentions have relied on extrapolations from other ocean regions, or from shallow waters within the region; until recently there had been very little direct study of impacts of the deep sea fisheries of the Mediterranean (on this subject, compare Palanques *et al*., 2006; Martín *et al*., 2008; Dimech *et al*., 2012; Puig *et al*., 2012 and subsequent publications stemming from that work; as well as Pusceddu *et al*., 2014, and Almeida *et al*., 2016). The deep fisheries of the region are too incompletely known for the magnitudes of impacts to be judged effectively by inter-regional comparisons.

Impacts on sensitive deep sea habitats including VMEs no doubt occur, as well as on other species taken as bycatch, but their extent and severity are still unknown. To prevent and manage these potential impacts, in 2018 GFCM endorsed a list of VME indicators (features, habitats and taxa), as well as a suite of technical measures addressing the management of deep-sea fisheries proposed by their SAC within its area of competence. Member States are encouraged to apply their own control measures. Nevertheless, GFCM has been using FRA designation as a multipurpose spatial management tool to restrict fishing activities in order to protect sensitive deep-sea habitats, such as VMEs and essential fish habitats since 2005 (EFH; FAO, 2019a). Up to 2018, eight delimited FRAs have been established to protect EFHs and/or VMEs from the significant adverse impact of certain fishing activities.

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11. North Pacific Ocean

FAO Major Fishing Areas 61 and 67, plus portions of Areas 71 and 77

SUMMARY

The North Pacific Ocean is made up of the open ocean and two high seas enclaves: the "Peanut Hole" in the Sea of Okhotsk and the "Donut Hole" in the central Bearing Sea. Both these enclaves had productive pelagic fisheries for walleye pollock, which at one time supported the world's largest whitefish fishery. The open ocean is typically too deep for bottom fishing, but there are various seamounts and seamount chains that rise to fishable depths and support some demersal fisheries. Most notable are the Emperor Seamount Chain and Hawaiian Ridge in the western North Pacific, which are exploited by bottom trawls, bottom set gillnets and longlines for alfonsino, North Pacific armourhead and other species – though catches vary greatly from year to year. There are also numerous seamounts in the eastern North Pacific; some of these are exploited for sablefish using bottom-set pots, though annual catches are small.

In 2016, catches with bottom fishing gears in the high seas of the Northwest Pacific Ocean amounted to an estimated 6 592 tonnes, comprised almost entirely of alfonsino and North Pacific armourhead, with small amounts of rockfish, mirror dory and warty oreas on the western side. The catch in the northeast Pacific is tiny by comparison: it amounted to an average of only 37 tonnes of sablefish per year for 2014–2018 (Table 11.1).

TABLE 11.1
High seas bottom fisheries catch (tonnes) in the North Pacific for 2016

Gears	Principal grounds	Flag states	Target species	2016 catch
Bottom trawl	Emperor Seamounts	Japan, Republic of Korea	North Pacific armourhead	226
			alfonsino	4 908
			others	554
Gillnet	Emperor Seamounts	Japan	North Pacific armourhead	8
			alfonsino	21
			others	717
Longline	Emperor Seamounts	Russian Federation	rockfish	118
			others	3
Trap & longline	NE Pacific seamounts	Canada	sablefish[1]	37
TOTAL				6 592

[1] average annual value for 2014–2018.
Source: www.npfc.int ; Sablefish: DFO, Canada, personal communication.

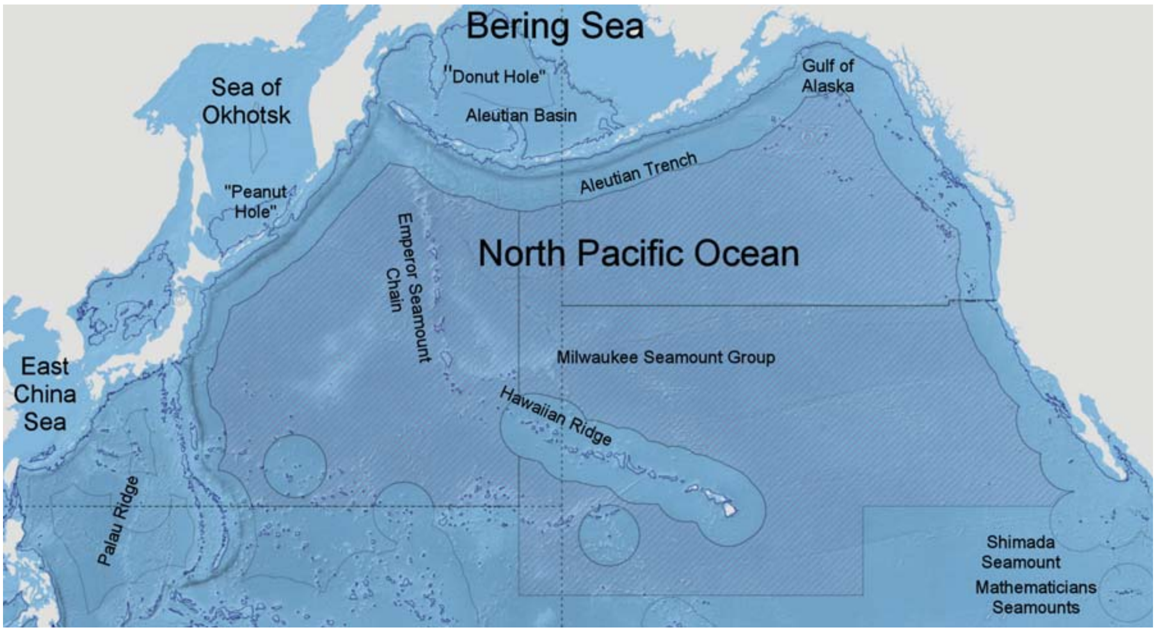
GEOGRAPHICAL DESCRIPTION

The Pacific Ocean is by far the largest area of sea on our planet, covering more than a quarter of the Earth's surface. For the purposes of this review it is divided, somewhat arbitrarily, on the 10° N parallel. The northern region is otherwise bounded by the continental landmasses of Asia and North America, in addition to the Bering

Strait (Figure 11.1). The continental shelves are narrow to very narrow east of 155° W, and all the off-shore islands north of the tropics are located on those shelves. As a consequence the national EEZs form a narrow fringe and there are no continental shelf or slope areas in the high seas. Conversely, to the west of 155° W, a series of island arcs and peninsulas extends from the Alaskan Peninsula to the Marianas via the Aleutians, Kamchatka, the Kuriles, and the main islands of Japan and the Bonin group. The EEZs around those islands and peninsulas form a continuous band, the outer boundary of which delimits the major high seas portion of the North Pacific.

The latter area comprises a vast and almost unbroken expanse of deep ocean and high seas, stretching from 200 nautical miles off the coast of Kamchatka to the same distance off Costa Rica (nearly 10 000 km); and similarly from off the Caroline Islands to 200 nautical miles from the coast of British Columbia (about 7 500 km). In the furthest southwest, the EEZs around the islands of Micronesia (specifically Wake Island and the Marshalls) extend into the region. Otherwise, the high seas area is broken only by an extensive EEZ around the Hawaiian Islands, stretching from the main islands westwards to beyond the Date Line, and by much smaller EEZs around the only two other islands: Japan's Minami-Tori-shima in the west and Johnston Atoll, a territory of the United States of America, southwest of Hawaii.

FIGURE 11.1
Map of North Pacific Ocean showing the NPFC Convention area (shaded)



200 nautical mile arcs, 2 000 m isobath (GEBCO), FAO fishing areas.
Source: FAO VME Database, Mercator projection.

This enormous high seas area is far too deep for commercial fishing almost everywhere (Table 11.2); though it is dotted with seamounts, they provide less than 20 000 km² of seabed shallower than 1 000 m. Many are isolated features but there are also ridges, including three of particular importance. The Emperor Seamount Chain runs along the 170° E meridian from 33° N to meet the Aleutian Trench at 54° N – a length of more than 2 000 km. The Hawaiian Ridge extends northwest from Hawaii itself to meet the southern end of the Emperor Chain.[1] Except for the one lying furthest

[1] Both ridges share a common geological origin: sharp change in the relative motions of the oceanic plate and the underlying mantle "hot spot" led to the 60° angle between the axes of the two ridges.

TABLE 11.2
Area statistics for the North Pacific Ocean

Geographical area	Surface area (km^2)
Total sea area	60 418 00
Area of high seas	35 491 000
Area of high seas shallower than 200 m	1 000
Area of high seas shallower than 400 m	5 000
Area of high seas shallower than 1 000 m	20 000
Area of high seas shallower than 2 000 m	152 000

to the north, all of the Emperor Seamounts are in the high seas. By contrast, most of the Hawaiian Ridge has been enclosed within the EEZ of the United States of America since 1977. Only the C-H and Colahan seamounts, together with the Milwaukee group at the junction of the two ridges, lie more than 200 nautical miles from the nearest land: Kure Atoll. Many of the seamounts in the southern Emperor Chain/northern Hawaiian Ridge area are flat-topped guyots, which facilitated their exploitation by bottom trawls in the era before the development of specialized "hill fishing" techniques in the 1990s. Some are very large: the 500 m bathymetric contour around Koko Seamount surrounds an area of some 40 km × 80 km.

The third notable ridge is the East Pacific Rise, which lies on the 115° W meridian, in the southeastern corner of the region. Some of its seamounts are at fishable depths, one of which breaks the surface as Clipperton Island, immediately north of the 10° N parallel. In the nearby high seas, shoals of as little as 10 m and 20 m depth have been reported (including Ville de Toulouse Rock and Germaine Bank). Further west, the Mathematicians Seamounts chain likewise rises above the surface as *Las Islas Revillagigedo*, with a fishable bottom likely in the adjacent high seas, including on Shimada Seamount.

THE "PEANUT HOLE" AND "DONUT HOLE" HIGH SEAS ENCLAVES

To the north and west of the band of EEZs between Alaska and the Marianas there are exceptionally wide areas of continental shelf, deep ocean basins, seamounts, ridges, islands and trenches but, with the exception of four small high seas enclaves, these all fall under national jurisdiction.[2] The enclaves are the "Donut Hole" in the central Bering Sea, and the "Peanut Hole" in the Sea of Okhotsk, which is the world's only substantial high seas enclave entirely surrounded by the EEZ of a single coastal state. There are two further areas lying south of Japan and to the east of the Philippines. Both of the first two are set amid rich fishing grounds. The "Donut Hole" is extensive (2 300 000 km^2) and extends from the outermost continental shelf down the slope to oceanic depths. Much of it is too deep for bottom fishing. The "Peanut Hole" is narrow by comparison (480 km × 55 km, for a total area of 36 000 km^2) and lies at a depth of between 200 and 2 000 m, with most of its seabed below 1 000 m. The southern two enclaves are deep everywhere, though traversed by the Palau Ridge and dotted with seamounts.

ECOSYSTEMS AND RESOURCE SPECIES

Oceanographically, the North Pacific is a typical (perhaps the archetypal) hemispheric ocean basin, with its North Equatorial Current feeding a western-boundary current, the Kuroshio, which in turn supplies an eastward drift (the Kuroshio Extension), with the southward-flowing California Current completing the loop. There is a broad area of subtropical, oligotrophic water within that gyre.

[2] The trenches include the deepest of all: the Marinas Trench and its Challenger Deep.

Ecologically, phytoplankton production is often limited by the availability of iron, a micronutrient, rather than the major nutrients (nitrate, phosphate and silicate) which are controlling factors in other ocean areas. Otherwise, the North Pacific presents textbook examples of deep-ocean ecosystems.

As is the case in other parts of the world ocean, the region's major demersal resources are found on continental shelves and upper slopes at temperate and high latitudes. The Pacific hake of the California Current ecosystem, analogous to the Merluccid hakes of other regions, have supported landings of over 300 000 tonnes in some years and continue to be fished, apparently sustainably (Methot and Dorn, 1995; Hamel *et al*., 2015). Several dozen discrete species of Sebastinid rockfishes are exploited along the arc of the North Pacific coastal and shelf waters, from off California to the East China Sea. Many of the species are caught inshore, but principal resources such as Pacific Ocean perch are concentrated at shelf-break and upper-slope depths. The rockfishes tend to be long-lived, with the maximum observed lifespans of many species stretching to several decades or over a century. Indeed the highest known age of any teleost, validated at 205 years, was read from the otoliths of a rougheye rockfish (Love *et al*., 2002; Beamish *et al*., 2006). This extreme longevity has allowed the resource to accumulate high biomasses, which briefly supported large catches, but left the fish vulnerable to swift depletion as fisheries developed. Indeed, some rockfishes have been severely overfished (e.g. Gunderson, 1984; Moore, 1999). Most notable of all, historically the walleye pollock has supported the world's largest whitefish fisheries, with a global catch that exceeded 6 750 000 tonnes in 1986, and has remained between 2 500 000 and 3 300 000 tonnes since the turn of the century (FAO, 2019). Exploited from the Gulf of Alaska to Japan, the principal grounds are in the Bering Sea and the Sea of Okhotsk. While pollock are typically demersal, there was a purely pelagic population in the central Bering Sea (Bailey, 2011), analogous to the blue whiting of the Norwegian Sea and adjacent areas, and to the Sebastinid redfish of the Irminger Sea.

Almost all of those rich fisheries fall under national jurisdiction, but the range of the central Bering Sea pelagic pollock included the "Donut Hole" and a major international fishery developed there during the 1980s (Bailey, 2011). Early on in the following decade the fleet moved to the "Peanut Hole" in the Sea of Okhotsk and – presumably – to its northern end in particular, as that is the only area where pollock are densely distributed (Volvenko, 2014). There, concentrated fishing effort could crop straddling-stock fish and so draw on production in the Russian Federation EEZ. The "Peanut Hole" pollock fishery was short-lived but produced a substantial catch (Kotenev and Bulatov, 2009).

Elsewhere in the region's high seas, bottom-fishery resources are necessarily seamount species. As in other regions, seamounts in the Pacific's tropical latitudes are generally unproductive. In practice, only the southern portion of the Emperor Seamount Chain and the northern end of the Hawaiian Ridge are proven to support substantial resources. A variety of species has been taken from the Emperor and Hawaiian Ridge seamounts including alfonsino, warty oreo and even crab (Figure 11.2). However, the economic viability of fishing so far from landing ports has been built on a single, most unusual species – North Pacific armourhead.

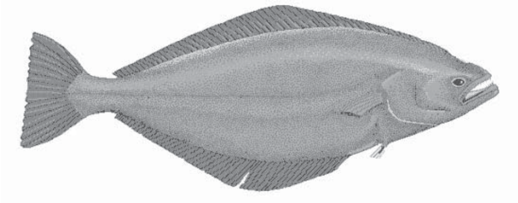
Adult North Pacific armourhead, which are bottom-associated if not fully demersal, occur on the continental slopes on both sides of the North Pacific but are only abundant on the southern-Emperor/northern-Hawaiian seamounts. However, the species has a prolonged epipelagic juvenile phase, lasting from 2–4.5 years, during which the young fish can be found broadly distributed between the adults' range and the North American continent. After settling on the seamounts and their recruitment to the adult population, North Pacific armourhead cease growing and gradually lose weight – so much so that they become visibly less deep-bodied (the older adults once being named "slender armourhead"). Thus, although the fish do continue to feed as

FIGURE 11.2
Principal demersal resource species of the high seas of the North Pacific

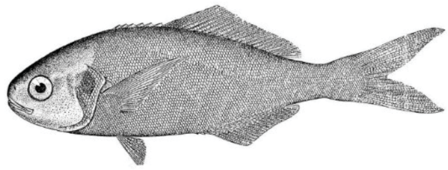
red coral *Corallium rubrum*[1]

tanner crab *Chionoecetes tanneri*[2]

Greenland halibut *Reinhardtius hippoglossoides*[3]

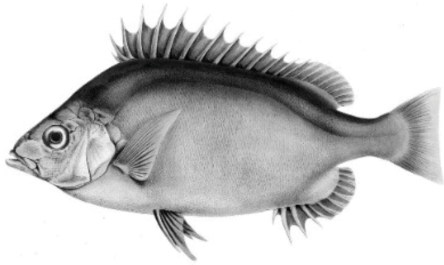


Japanese butterfish
Hyperoglyphe japonicas[4]

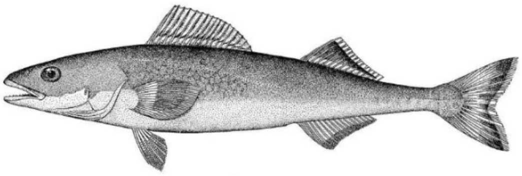


mirror dory *Zenopsis nebulosi*[1]

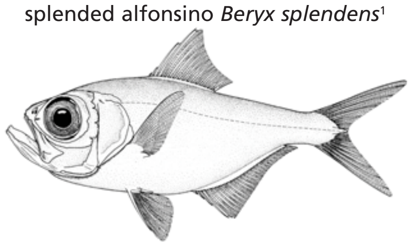
North Pacific Armourhead
Pseudopentaceros richardsoni[5]



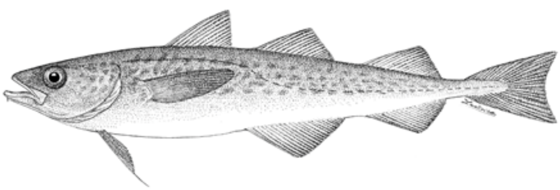
sablefish *Anoplopoma fimbria*[6]



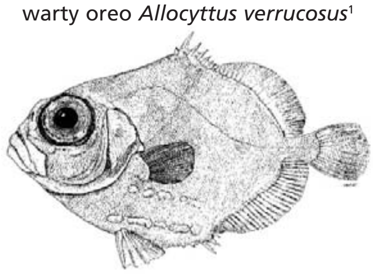
splended alfonsino *Beryx splendens*[1]



walleye pollock *Theragra chalcogramma*[1]



warty oreo *Allocyttus verrucosus*[1]



Source:
[1] Food and Agriculture Organization of the United Nations, Original Scientific Illustrations Archive.
[2] Photo by A.C. Tatarinov sv.wikipedia.org/wiki/Chionoecetes_tanneri#/media/Fil:Chionoecetes_tanneri.jpg CC BY-SA 3.0
[3] www.fao.org/fishery/species/2544/en
[4] Jordan and Hubbs (1925).
[5] Smith (1849).
[6] Jordan and Evermann (1900).

adults, their biomass on the southern-Emperor/northern-Hawaiian seamounts is not supported by primary production and prey availability in that area alone. Rather, it draws on production across a much wider range, cropped by the juveniles and then carried to the seamounts, in the form of fat reserves in the bodies of the fish as they migrate (Kiyota *et al*., 2016).

Adult North Pacific armourhead have been observed on the seamounts at depths of 150–1 500 m but are only abundant above 500 m. They do not live very long after settlement, apparently only 4–5 years; hence their natural mortality rate is high, with one estimate suggesting over 0.5 per year. Thus, the species cannot accumulate large biomasses through the recruitment of multiple year-classes over decades. Yet, when the resource was first fished on the southern-Emperor/northern Hawaiian seamounts approximately 500 000 tonnes were taken in less than ten years, most of it in just four seasons (Kiyota *et al*., 2016). It thus appears that recruitment to the adult population can be very strong, though likely subject to high inter-annual variability.

It is likely that other seamount species support fisheries within EEZs around the periphery of the North Pacific, as well as in the zone around Hawaii. Some of those fisheries likely spill over into the high seas where seamounts can be fished just beyond the 200-nautical-mile boundaries, though their high seas catches may be small everywhere. However, the only such fishing that can be confirmed is on seamounts immediately outside the Canadian EEZ. There is some suggestion that the early trawl fisheries for Sebastinid rockfishes explored those seamounts, but the only modern fishery has been for sablefish.

MANAGEMENT OF HIGH SEAS BOTTOM FISHERIES

North Pacific Fisheries Commission (NPFC)

There was no RFMO with competence over the bottom fisheries conducted in the North Pacific when the UN General Assembly adopted its Resolution 61/105 in 2006. However, negotiations concerning such an organization had begun, and an interim body operated to collect scientific information and provide advisory measures relating to bottom fisheries. Preliminary Consultations (2006), Formal Consultations (2006–2011) and Preparatory Conferences (2011–2015), together with various scientific meetings throughout this period, played an important role in developing the framework for the area's subsequent regional fisheries management. The Convention on the Conservation and Management of High Seas Fisheries Resources in the North Pacific Ocean was adopted in 2012 by five signatories: Canada, China, Japan, Republic of Korea, and the Russian Federation; it entered into force in July 2015, thus establishing the North Pacific Fisheries Commission (NPFC). The United States of America and Vanuatu have since become contracting parties, while Taiwan Province of China signed to become a participating member. The commission held its first meeting in September 2015. A Scientific Working Group was established in 2007 and subsequently created specialized groups on, among other aspects, North Pacific armourhead and vulnerable marine ecosystems (VMEs). In 2016 those bodies were reconstituted as the NPFC Scientific Committee and specialized "small scientific committees", each then holding a first meeting in its new status.

The convention area is limited to the principal high seas portion of the North Pacific, excluding the four enclaves in the north and west of the region. Its southern boundary is the 20° N parallel, except between 140° W and the Date Line, where the boundary is at 10° N. The objective of the convention is to ensure the long-term conservation and sustainable use of the fisheries resources in the convention area, while protecting the marine ecosystems of the North Pacific Ocean in which those resources occur. The NPFC oversees all living resources within the convention area except marine mammals, reptiles and birds, benthic species subject to the sovereign rights of coastal states, catadromous fish, and other species covered by pre-existing international fisheries management instruments. In addition to the bottom fisheries of concern to the present review, the NPFC mandate gives it responsibility for pelagic fisheries targeting diverse commercial species including NPFC priority species such as Pacific saury, chub and spotted mackerels, Japanese sardine, neon flying squid and Japanese flying squid.

Interim conservation measures for the northwest Pacific (including the southern-Emperor/northern-Hawaiian seamounts) were adopted in 2007 and revised over the following two years, though they were inevitably generalized and relied on flag state action for their detailed development. Parallel measures for the northeast were adopted in 2011. Formal measures were first introduced in 2016 (Table 11.3). In both subregions there are requirements for the national licensing of vessels fishing the high seas and for the submission of a vessel list to the interim secretariat. There are requirements for assessments of the impacts of fishing on VMEs, though they are differently worded in the measures applicable to each subregion. In the northwest, interim measures additionally require contracting parties to prevent the expansion of fishing effort beyond areas fished during 2002–2006, as well as avoiding an increase in capacity, potential impacts on ecosystems or the spatial extent of bottom fishing within the area. Bottom fishing is specifically limited to seamounts south of 45° N. However, each of those requirements can be waived if the new fishing activity is shown not to have significant adverse impacts and if it conforms to an exploratory protocol – requirements that also apply to any fishing with new gears. In all situations, bottom fishing is subject to a protocol covering encounters with corals. There is a requirement to carry observers and to share information among the parties. For the northeast, there is a ban on directed fishing for corals or VME-indicator species, as well as a requirement for 100 percent observer coverage. At the national level, Japan requires that bottom-set gillnets stand 1 m above the seabed when deployed from vessels under its flag. Canada imposes a seasonal closure on its seamount fishery, opening only from April to September. It authorizes only one vessel per calendar month to fish the "southern seamounts", a unit which includes all of those fished in the high seas while requiring the use of trap or longline gear and imposes, among other requirements, a minimum fish-size limit and monthly landing limits (Du Preez, 2018).

The NPFC Scientific Committee met for the first time in 2016, but that followed a decade of meetings of the preceding Scientific Working Group. Both have and had access to the advanced fisheries science capabilities of the commission's parties. However, the seamount resources and fisheries of the North Pacific pose formidable challenges to both research and stock assessment. Therefore, while the Scientific Working Group undertook preparatory work, stock assessments have not been prepared.

Japan has maintained a series of surveys of the existing fishing areas on the southern Emperor/northern Hawaiian seamounts since 2009 (Dionne, 2016) but little information on the results has been made public. While Russian Federation programmes in the Sea of Okhotsk appear to include coverage of the "Peanut Hole", no other ongoing fisheries research or monitoring programmes are known in any of the region's other high seas enclaves.

The bottom fished areas in the northwest subregion are limited to just 13 seamounts: Suiko, Showa, Youmei, Nintoku, Jingu, Ojin, Northern Koko, Koko and Kinmei in the Emperor Chain; Yuryaku and Kammu in the Milwaukee group; and Colahan and C-H on the Hawaiian Ridge (Figure 11.3). The three parties that have been or remain active in the bottom fisheries of the northwest Pacific subregion – Japan, the Republic of Korea and the Russian Federation – agreed to close C-H Seamount to their bottom fishing vessels in 2009 to protect North Pacific armourhead. They also closed an area on the southeastern side of Koko Seamount, where higher densities of corals have been observed. On all of the seamounts, Japan and the Republic of Korea further restrict fishing under their flags by setting a maximum depth of 1 500 m (Dionne, 2016). The bottom-fished seamounts in the northeast Pacific subregion were only formally identified in 2017, though it is unclear how much active fishing is currently occurring on these (Figure 11.4).

TABLE 11.3
Measures adopted by NPFC (including in the interim phase for 2006–2014) from 2006 to present pertaining to high seas bottom fisheries

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Bans on directed fishing													
Bottom fisheries prohibited (November and December)											W	W	W
Corals (covering four orders)				(W)	→	(W,E)	→	→	→	→	W,E	W,E	W, →
Effort and TAC restrictions													
North Pacific Armourhead – catch limit Japan											W	W	W
North Pacific Armourhead – advisory catch limit for Japan and Korea according to recruitment													W
Effort level limitation (Bottom fishing)											W,E	W,E	W, →
Other bottom fishing measures													
Fished areas identified				(W)	→	→	→	→	→	→	W	W	W
Fishing prohibited north of 45° N		(W)	→	(W)	→	→	→	→	→	→	W	W	W
Fishing prohibited below 1 500 m											W	W	W
Move-on rule (to protect VMEs)				(W)	→	→	→	→	→	→	W,E	W,E	W, →
Threshold for VME indicator catch (corals)											W,E	W,E	W, →
VME closures											W	W	W
Exploratory fishing protocol				(W)	→	(W,E)	→	→	→	→	W	W,E	W, →
Gear restrictions (gillnets > 70 cm above seafloor)											W	W	W
Gear restrictions (trawl mesh size)													W
Observers											W	W	W

The above table is taken from interim measures and CMMs XXXX-05 and CMMs XXXX-06.

"W" and "E" refer to the western and eastern North Pacific, respectively.

Blank cell: no measure

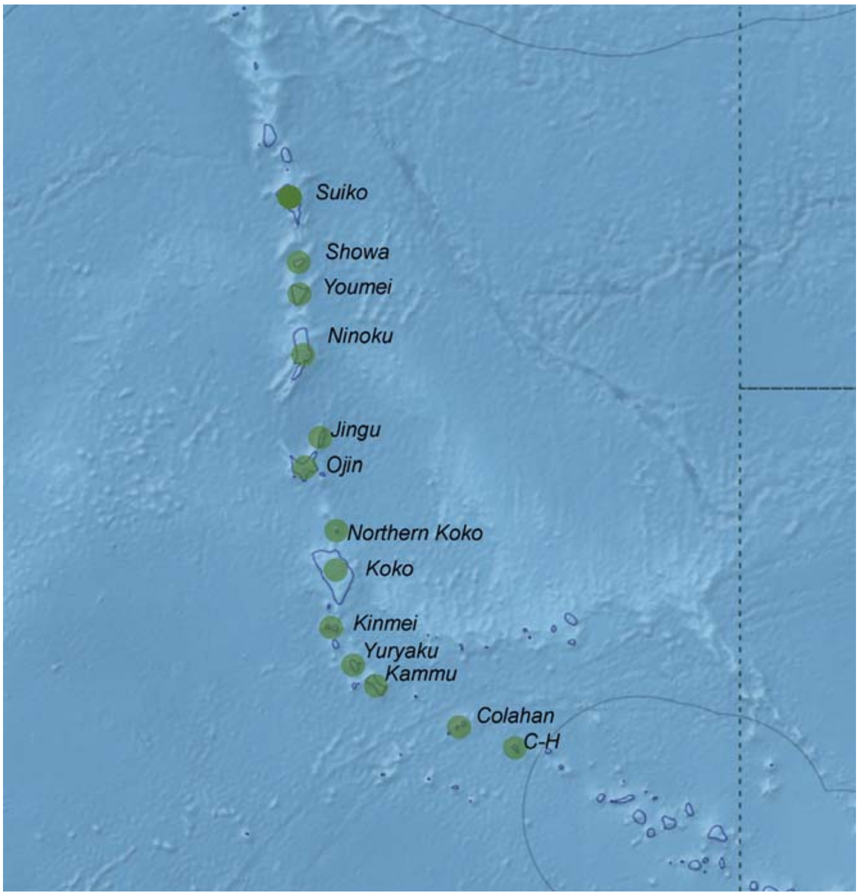
→: Measure rolled over to next year

Parentheses: Measures non-binding during the NPFC interim period 2006–2014

Note that not all measures were in force for the complete year (see NPFC website for details)

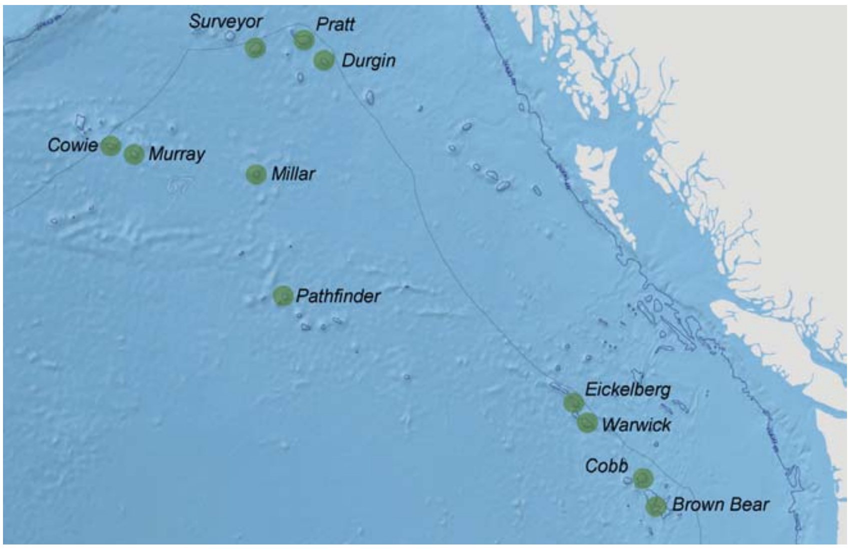
Source: www.npfc.int/active-conservation-and-management-measures

FIGURE 11.3
Areas in the northwestern Pacific where bottom fishing has been recorded by NPFC



Source: FAO VME Database, shading and names added.

FIGURE 11.4
Areas in the northeastern Pacific where bottom fishing has been recorded by NPFC



Source: FAO VME Database, shading and names added.

The first applications to NPFC for exploratory fisheries were received in 2017, and these are in the process of being reviewed. The vast high seas area of the North Pacific is de facto closed to bottom fishing, with the very few exceptions to the 13 aforementioned southern Emperor/northern Hawaiian seamounts, the few fished seamounts outside the Canadian EEZ and the four high seas enclaves.

The NPFC member flagged vessel registry currently includes the following bottom fishing vessels:[3] five trawlers and one gillnetter from Japan, five trawlers from China, and three trawlers and two longliners from the Republic of Korea. Most are between 500–2 000 GRT but six trawlers are larger, up to 5 550 GRT. The NPFC also has an IUU vessel list which contained reported sightings of 27 vessels in 2017 and 2018 (NPFC, 2018).

Convention on the Conservation and Management of Pollock Resources in the Central Bering Sea (CCBSP)

In the 1980s, a midwater trawl fishery for pelagic walleye pollock developed very rapidly in the Bering Sea "Donut Hole". It is still unclear whether, or to what degree, the fish were distinct from the resources in the adjacent EEZs of the United States of America and the former USSR. High seas catches collapsed in 1992 and a moratorium was introduced the following year (Vicuña, 1999; Bailey, 2011). This led to a convention, which was signed in 1994 and entered into force in 1995, the objectives of which were essentially to restore the pollock and enable their optimal exploitation in future. The parties were and continue to be the two coastal states of the Russian Federation and the United States of America, in addition to the four flag states primarily active in the high seas enclave: China, Japan, the Republic of Korea and Poland. While the parties have met annually since 1996 (latterly by virtual conference) and scientific workshops were held from 1997 until 2005, the high seas pollock resource has not recovered and the fishery has not been reopened.

The focus of the CCBSP is restricted to walleye pollock in the "Donut Hole", where that species is pelagic. Demersal fisheries in that enclave lack multilateral fisheries management, though only a small part of its extent is shallow enough for commercial bottom fishing.

Sea of Okhotsk "Peanut Hole" bilateral agreements

In 1991, as opportunities to trawl for walleye pollock in the "Donut Hole" declined, international attention turned to the "Peanut Hole", which lies in a part of the Sea of Okhotsk long closed to local trawlers. The following year the fleets of China, the Republic of Korea, Panama and Poland reported pollock catches from the "Peanut Hole" that approached 700 000 tonnes. The spectre of the contemporaneous collapse of the "Donut Hole" pollock raised fears for the ecologically and economically important Sea of Okhotsk resource. There were also further concerns about foreign-flag trawlers lingering in the high seas enclave and making incursions into the Russian EEZ, at a time when budgets for fisheries enforcement were scarce (Goltz, 1995; Kotenev and Bulatov, 2009).

The Russian Federation claimed a special interest in the "Peanut Hole" pollock, since they are part of a straddling stock that primarily occurs within the adjacent EEZ. In April 1993, the Russian Federation therefore unilaterally decreed a temporary closure of the central Sea of Okhotsk, pending international agreement on the management of the fishery. The prohibition was not directly enforced on foreign-flag vessels but restrictions were placed on port access and at-sea replenishment for those who did not comply. A conference was convened that same year but did not lead to multilateral consensus. Rather, by 1995 Japan had withdrawn from the area, while the

[3] https://www.npfc.int/compliance/vessels

Russian Federation had licensed Chinese, Korean and Polish vessels to fish within its EEZ in the Sea of Okhotsk – where the grounds are more productive for pollock – under bilateral agreements which required their acceptance of the closure and of coastal-state management. This solution was similar to that applied in the Barents Sea "Loophole". The "Peanut Hole" has thus effectively been closed to pollock trawling since 1995 (Goltz, 1995; Elferink, 2001; Kotenev and Bulatov, 2009).

Other areas of high seas in the region

The two tropical high seas enclaves in the southwest of the region have no multilateral fisheries management arrangements with competence over bottom fishing. Such arrangements are equally lacking in the three parts of the principal high seas area which lie south of the NPFC convention area. West of the Date Line, there are two areas of high seas between the 10° N boundary of the region and the 20° N limit of NPFC competence, lying east and west of the EEZs around Wake Island and the Marshalls. East of 140° W a third, similar area extends from the NPFC convention area boundary at 20° N to the limit of the SPRFMO convention area at 2° N, thus overlapping into what is here considered the South Pacific region. While no bottom fishing has been reported in any of those five areas there are fishable seamounts, at least on the East Pacific Rise.

DESCRIPTION OF HIGH SEAS BOTTOM FISHERIES

Continental shelf and slope

Bottom fishing in what are now the high seas of the North Pacific region likely began before 1960. The former USSR expanded its trawler fleet after 1945 and the Japanese fleet was rebuilt at the same time; indeed, after the signing of a peace treaty in 1951, it was able to return to what were then international waters. It reached the eastern Bering Sea by 1954, where it was joined by vessels from the former USSR from 1959 (Bailey, 2011). By then it is likely that some fishing had occurred along the shelf breaks in the "Donut Hole" and "Peanut Hole", though those areas had no special significance until later and hence there was no particular recording of the activity.

"Donut Hole" – walleye pollock

Little of the "Donut Hole" has seabed at fishable depths, while the grounds elsewhere in the Bering Sea are more productive. As a result there the incentive to fish in what is now the high seas enclave was limited. During the 1970s, however, the central Bering Sea pelagic population of the normally bottom-associated walleye pollock was discovered in the waters over the deep Aleutian Basin. A Japanese midwater trawl fishery had begun there by 1981, taking pre-spawning fish in winter and the females for their roe, while the males and the female carcasses were processed for surimi and fish meal. At much the same time, the Alaskan crab fishery declined and the United States of American crab industry took advantage of a favourable legal environment to convert its fleet to groundfish fishing. The resulting "Americanization" of the pollock fishery within the United States of America EEZ displaced vessels trawling for the species under other flags into the "Donut Hole". Reported catches peaked at 1 500 000 tonnes in 1989, though some of that total may have come from IUU fishing within the United States of America and former USSR EEZs. In retrospect, it is now known that the biomass of pelagic pollock was declining as catches rose, though it is still unsure whether resource productivity also fell and, if so, why. By 1992, resource biomass was down to well below 10 percent of its pre-fishery level, while catches had dropped to 10 000 tonnes. The fishery was closed the following year and has not reopened (Bailey, 2011).

Low levels of bottom fishing for Greenland halibut and perhaps crab may still occur in the "Donut Hole", but catches are probably low. There are no management restrictions on fishing for demersal resources, other than walleye pollock.

"Peanut Hole" – walleye pollock

Long before the "Donut Hole" fishery emerged the former USSR had closed the central Sea of Okhotsk – including what is now the "Peanut Hole" – to its own trawlers while pursuing a major walleye pollock fishery elsewhere in that sea. In 1991, as opportunities for trawlers in the "Donut Hole" became more limited, vessels under the flags of China, the Republic of Korea, Panama and Poland turned to the "Peanut Hole". The following year, the pollock catch taken in that enclave reached 698 000 tonnes, raising the annual catch from the entire Sea of Okhotsk to nearly 2 000 000 tonnes. It is not known whether some (or even most) of the "Peanut Hole" catch was taken by midwater trawls working close to the seabed in the manner now common in walleye pollock fisheries. However, the high seas catch was taken from a typical, bottom-associated population, unlike the purely pelagic resource harvested in the "Donut Hole". After 1991, the "Peanut Hole" catch fell swiftly as the Russian Federation exerted its management primacy and the fisheries closure covering both the enclave and the rest of the central Sea of Okhotsk was effectively restored from 1995. The overall catch from the pollock resource in the sea rose to new records in 1995 and 1996, the latter year's slightly surpassing 2 000 000 tonnes. It has since fallen to approximately 500 000 tonnes annually, in part because of the effects of environmental variability on recruitment (Goltz, 1995; Kotenev and Bulatov, 2009).

While the "Peanut Hole" pollock fishery lasted less than five years, its 1992 catch alone was approximately equal to the combined reported landings of all other high seas bottom fisheries in the North Pacific region, summed over their entire histories to date.

Little information is available on other fisheries in the "Peanut Hole", though it has been reported that two Japanese vessels currently target Greenland halibut there. (Both longline and trawl fisheries for that species have operated in the adjacent Russian EEZ; Balykin and Terentyev, 2004.) There have also been recent media reports of crabbing. In 2014, the seabed in the enclave was formally recognized as part of the Russian Federation's extended continental shelf by the United Nations Commission on the Limits of the Continental Shelf, confirming national jurisdiction over fisheries for such benthic species.

Fisheries on the Emperor Seamount Chain and the northern Hawaiian Ridge

North Pacific armourhead and alfonsino

The only known bottom fishing in the high seas of the North Pacific ocean is confined to the 13 southern-Emperor/northern-Hawaiian seamounts that are considered to be bottom fishing areas by NPFC, where the summits have been fished with bottom trawls and the summits and slopes by bottom gillnets. Those support three distinct fisheries identified by the major gear types (bottom trawl, gillnets and longlines) and to a lesser extent pots (Table 11.4, Figure 11.5). The southern portion of Koko Seamount and C-H Seamount, towards the southeastern end of the "high seas" part of the chain, have been closed to bottom fishing since 2009: in the first instance through a voluntary agreement between Japan, the Republic of Korea and the Russian Federation, and since 2016 by NPFC (though exploratory fishing is permitted).

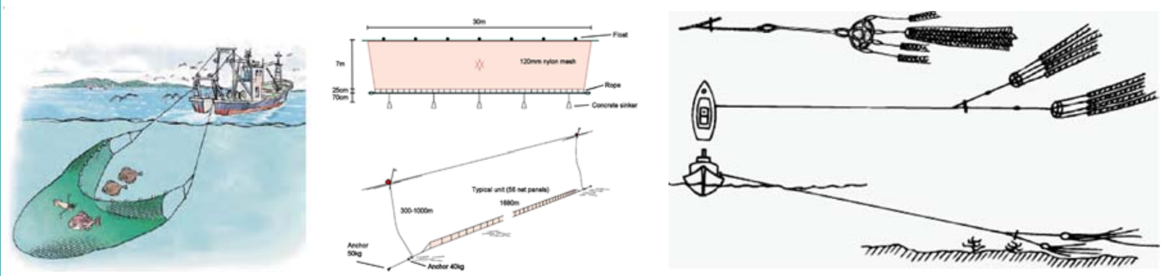
In 1967, trawlers from the former USSR discovered aggregations of adult North Pacific armourhead on the southern portion of the Emperor Seamount Chain and

TABLE 11.4
Target species catch (tonnes), fishing effort (fishing-days) and fleet numbers on the Emperor Seamounts and Hawaiian Ridge fisheries for 2002–2017

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
TRAWL																
Armourhead	359	449	12 826	6 500	1 725	1 696	6 765	1 217	21 616	3 707	24 110	3 230	1 844	886	226	361
Alfonsino	2 815	2 005	2 461	5 315	4 072	3 340	1 304	1 163	899	2 101	745	2 576	4 080	2 881	4 908	3 941
Mirror dory	113	75	44	215	144	151	118	286	66	130	81	214	68	149	82	69
Butterfish	35	53	46	193	46	27	91	15	75	296	324	147	124	175	27	18
Rockfishes	361	173	57	440	264	167	74	242	69	116	38	133	242	84	49	24
Others	3 411	3 202	3 220	2 022	2 958	2 759	749	2 009	378	1 190	301	2 148	2 274	789	396	296
Total catch	7 094	5 956	18 654	14 685	9 209	8 139	9 102	4 931	23 103	7 540	25 600	8 448	8 632	4 964	5 687	4 709
Effort	803	681	1029	1 160	1 072	1 257	1 138	939	1 036	852	1 050	1 047	1 094	868	596	385
Vessels	5	4	9	15	9	8	7	8	7	7	7	8	8	6	5	3
GILLNET																
Armourhead	0	0	869	659	124	116	498	43	1006	145	1350	87	32	2	8	53
Alfonsino	20	0	152	242	375	192	261	229	158	55	45	226	64	9	21	33
Others	385	67	87	90	324	456	172	271	85	381	318	301	651	1027	717	564
Total catch	405	67	1108	991	823	763	931	543	1248	581	1713	613	746	1039	747	650
Effort	208	19	139	193	204	211	198	180	198	180	183	152	165	161	192	145
Vessels	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
LONGLINE																
Rockfishes	161	20	7	0	327	0	344	165	0	0	0	0	191	158	118	0
Others[1]	17	0	19	0	137	0	14	15	0	0	0	0	8	2	3	90
Total catch	177	20	26	0	464	0	358	180	0	0	0	0	198	160	121	90
Effort	14	0	56	0	0	0	92	83	0	0	0	0	61	59	58	61
Vessels	2	1	2	0	0	0	2	2	0	0	0	0	1	1	1	1
POTS																
Crab	43	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vessels	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[1] mostly skilfish (*Erilepsis zonifer*) in 2014–2017.
Source: www.npfc.int

FIGURE 11.5
Fishing gears used in the high seas of the north Pacific Ocean to catch demersal species: (a) Trawl net, (b) Japanese gillnet, as used in the seamount fisheries, and (c) Japanese tanglenet dredge, (similar design to those formerly used in high seas red coral fishery)



(a) **(b)** **(c)**

Source: (a) and (b) – Fisheries Agency of Japan, (c) – Home page of All Kochi Coral Fishery association.

a commercial fishery followed.[4] In 1968, catch rates averaged nearly 12 tonnes in a half-hour tow. Japanese trawlers joined the fishery in 1969 and the combined catch peaked at nearly 163 000 tonnes in 1970 (Figure 11.6). It dropped by an order of magnitude the following year, then recovered to a new record in 1973 with a catch of over 178 000 tonnes of North Pacific armourhead (150 000 tonnes taken by vessels from the former USSR). Japanese and Korean longline and vertical line vessels joined the fleet that same year, though they primarily targeted alfonsino and skilfish.[5] Thereafter, North Pacific armourhead catches fell off precipitously, averaging under 40 000 tonnes annually for three years and then dropping again to only 3 100 tonnes in 1977 (2 900 tonnes taken by Japanese vessels), by which time the former USSR had withdrawn from the fishery. Most of the catch had come from just four seamounts: Yuryaku and Kammu in the Milwaukee group, plus Colahan and CH on the Hawaiian Ridge, each of which has a summit depth of 200–400 m.

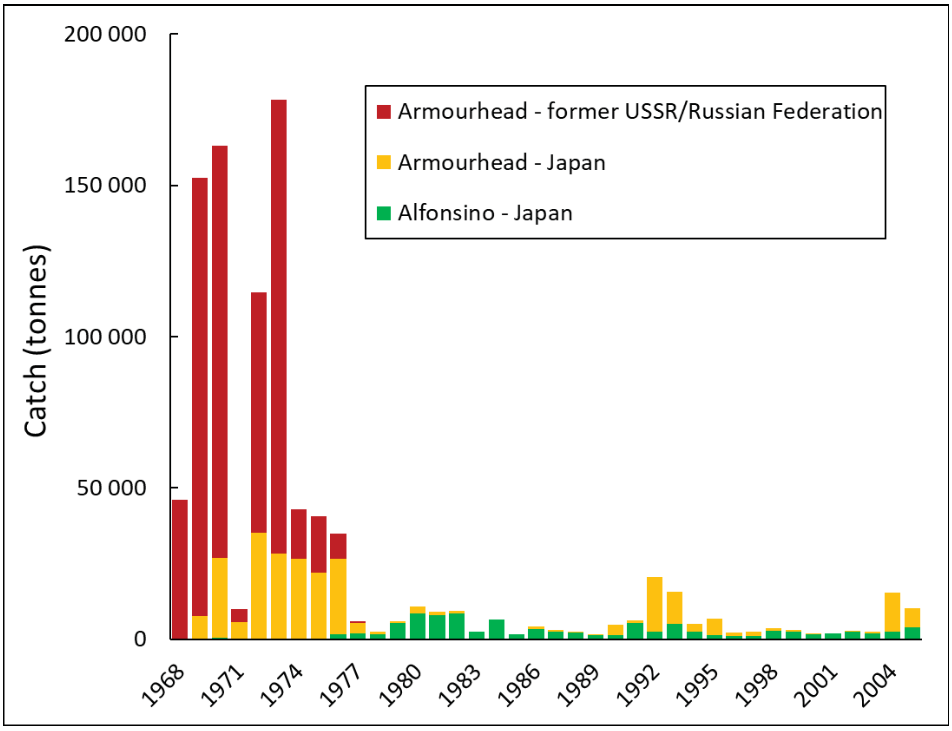
An alfonsino trawl and gillnet fishery developed on the southern Emperor and northern Hawaiian Ridge seamounts during the late 1970s and 1980s, mainly involving Japan and to a lesser extent the Russian Federation, as well as the Republic of Korea during the later 1998–2009 period. Catches approaching 10 000 tonnes were recorded in the early 1980s, though they have declined a little and now average around 1 000–5 000 tonnes per year (Figure 11.7) Trawling was mainly carried out at depths of 300–400 m and caught smaller individuals, whereas the gillnet fishery generally operated deeper at depths of 300–1 300 m and caught larger fish (Shotton, 2016).

Establishment of the EEZ by the United States of America in 1977 closed off opportunities for expansion southeastwards, down the Hawaiian Ridge, though it is unclear whether North Pacific armourhead and alfonsino resources occur in

[4] Belyaev and Darnitskiy (2005) reported that fish aggregations on these seamounts were known to Japanese fishermen in the 1950s. The seamounts themselves had certainly been mapped by Japanese hydrographers before 1952, some having been found independently by American ships during the Pacific war (Calgue *et al.*, 1980). If any commercial-scale fishing was attempted before 1968, no records of the catches are known. An American oceanographer, working in Tokyo, named several of the seamounts after ancient Japanese emperors and named the chain accordingly (Calgue *et al.*, 1980). Others are named after the ships which found them.

[5] A report from 1976 names the target species of the early Japanese longlining as alfonsino, (i.e. rockfish) and . The latter name usually refers to groupers. However, it has recently been suggested that the "rockfish" were spp. and the perhaps the Sebastinid – endemic to the Emperor seamount Chain and Hawaiian Ridge (NOAA, 2008).

FIGURE 11.6
Historic catches of North Pacific armourhead and alfonsino from seamounts along the Emperor Seamounts and Hawaiian Ridge



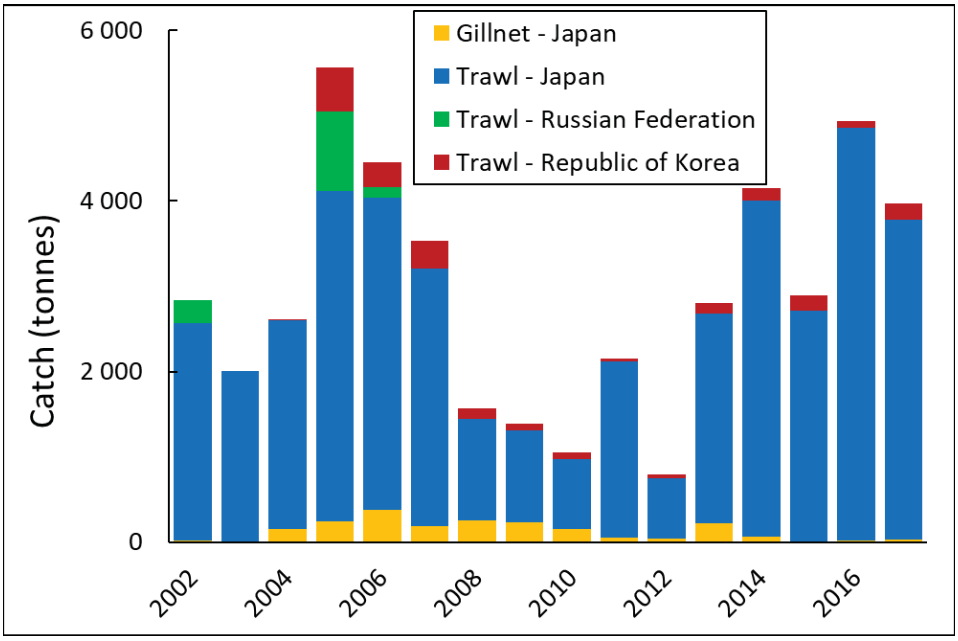
Catches by other nations and gears were very low during this period.
Source: Shotton, 2016 (redrawn from Figure 16 and Table 18); FAO, 2019 (data for armourhead catch by former USSR/Russian Federation for 1968–1970 and 1972–1975).

commercial quantities on the seamounts south of 30° N, which have shallower summits that extend into warmer water. The United States of America issued permits for Japanese trawlers to work on the Hancock seamounts (immediately inside the EEZ boundary) until 1984 but a moratorium was introduced two years later, in response to the pre-1977 depletion of North Pacific armourhead, and has been maintained since.[6]

The bottom trawl fishery has continued to provide most of the catch into the 2000s; it is dominated by Japan who fish mostly on Yuyaku and Kammu seamounts at 300–400 m depth (FAJ, 2008a). Russian trawlers have not taken part since 2008 but vessels from the Republic of Korea fish regularly. The principal resource species remains North Pacific armourhead but annual catches are highly variable, tracking recruitment (Figure 11.8). The best year since the mid-1970s was 2012, with a catch of more than 20 000 tonnes, but recruitments and catches have been poor since. Alfonsino provide annual catches of 1 000–4 000 tonnes, such that they can dominate over North Pacific armourhead in poor years (Figure 11.7). In 2008, the target species were splendid alfonsino and North Pacific armourhead, while broad alfonsino, Japanese armourhead, Japanese butterfish, skilfish, "scorpionfish" and others were taken as bycatch by Korean trawls (MFAAF, 2008); Japanese vessels took alfonsino, mirror dory and pencil cardinalfish (FAJ, 2008a). The number of trawlers involved is variable but in most years it has been seven or eight. In 2014, there were six Japanese vessels, of 52–66 m length, dropping to four vessels in 2016, plus two from the Republic of Korea

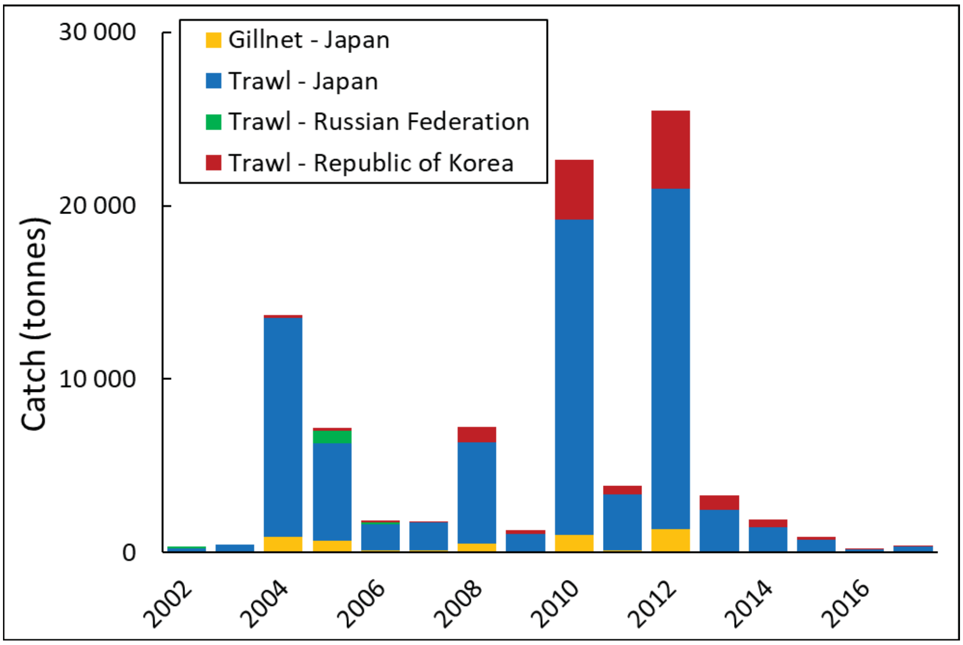
[6] In 2016, the United States of America extended its Papahānaumokuākea Marine National Monument to include its entire EEZ around the northwestern Hawaiian Islands and thereby placed the Hancock Seamounts inside a permanent "no-take" MPA.

FIGURE 11.7
Recent catches of alfonsino from seamounts along the Emperor Seamounts and Hawaiian Ridge



Source: www.npfc.int

FIGURE 11.8
Recent catches of North Pacific Armourhead from seamounts along the Emperor Seamounts and Hawaiian Ridge



Source: www.npfc.int

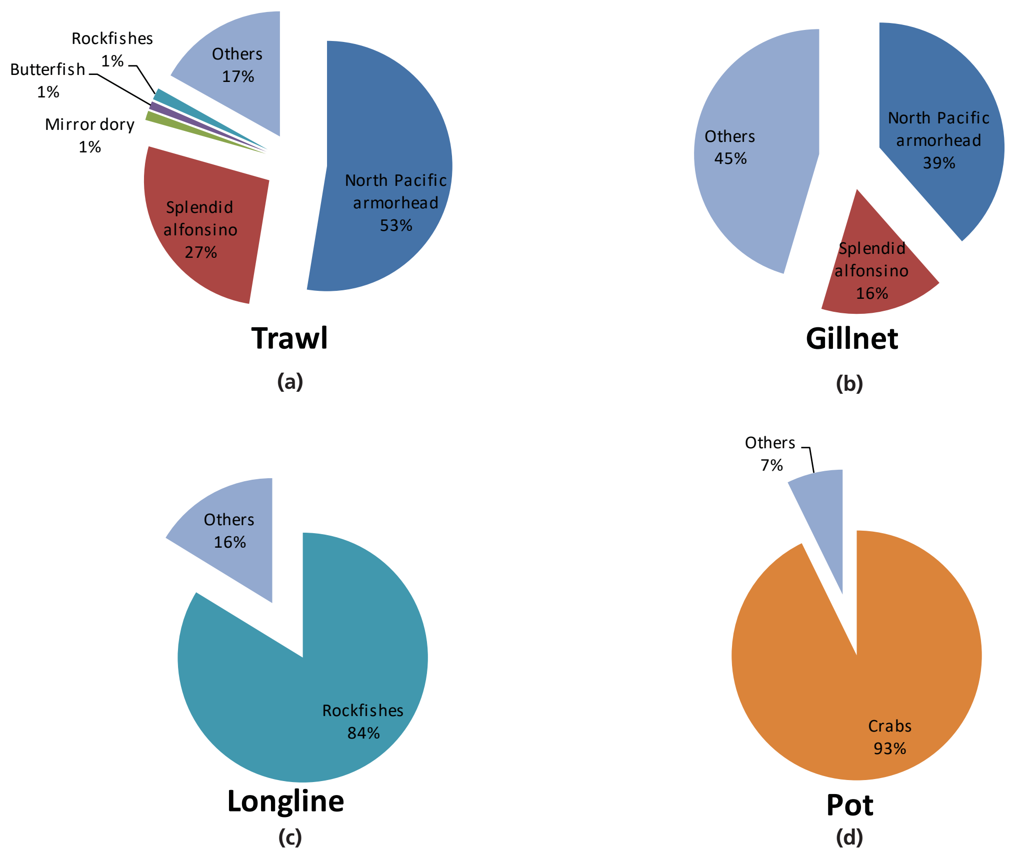
in both years (61 m and 80 m). The Japanese trawl catch amounted to 7 977 tonnes and 5 537 tonnes in 2014 and 2016 respectively, compared to catches of 656 tonnes and 150 tonnes respectively by the Republic of Korea. The percentages of the different species varied between these two years, with alfonsino forming the majority of the catch and North Pacific armourhead catches dropping dramatically. Unidentified fish remain a significant proportion of the catch, averaging 20 percent for the two years examined here (Table 11.4).

Nowadays the gillnet fishery is only undertaken by Japan, though only one vessel has been involved in each year since 2003. The Russian Federation withdrew from the fishery after 2001. Although alfonsino and North Pacific armourhead remain the nominal target species, they have come to represent a minority of the identified catch, amounting to only 96 tonnes and 29 tonnes of a total catch of 747 tonnes (in 2014) and 746 tonnes (in 2016) respectively. The bycatch includes warty oreo, mirror dory, butterfish and Sebastinid "rockfishes" and other unidentified species that amounted to almost 90 percent of the catch for the two years (Figure 11.9). Gillnetters of typically around 50 m in length and 750 GRT have worked Koko, Yuyaku, Kammu, Colahan seamounts, with some effort on Suiko and Kinmei. They mostly operate at 300–900 m depth but sometimes as deep as 1 500 m (FAJ, 2008b). C-H seamount was fished up to 2008.

Longlining vessels from the Republic of Korea ceased fishing on the seamounts in 2004 but two Russian longliners fished there in 2008 and 2009; a single vessel under that flag then fished in 2014 and 2015. In 2014 its catch amounted to 191 tonnes of "rockfishes" and 8 tonnes of assorted bycatch (Table 11.4)). Bensch *et al.* (2009)

FIGURE 11.9

Proportion of fish caught by bottom gears for: (a) trawl, (b) gillnet, (c) longline, and (d) pots, from the Emperor Seamounts and Hawaiian Ridge for 2002–2017 combined



Source: www.npfc.int

reported that the longliners which fished until 2004 targeted sharks, skilfish and "rockfish". The Russian longlining in 2008–2009 targeted "rockfish" (further identified as primarily *Helicolenus* spp., probably including *H.avius*), skilfish, alfonsino, North Pacific armourhead and grenadiers (*Coryphaenoides* spp.), with a bycatch of escolar, wahoo, dorado and codling (primarily *Physiculus* spp.), on Showa, Yomei, Nintoku and Koko seamounts. Again, the officially reported catch includes an average of 35 percent of unidentified species (Figure 11.9). Until 2008 (and perhaps subsequently), Russian longliners working the seamounts were 45–52 m vessels of about 1 300 GRT (Russia, 2008; NOAA, 2008).

High seas seamount fishing has therefore continued primarily under the Japanese flag, though vessels from the Republic of Korea, the Russian Federation and Taiwan Province of China have occasionally been involved. Since 1977, annual catches of pelagic armourhead have rarely exceeded 2 000 tonnes and in some years, such as 1983, there has been no fishing at all. The catch did exceed 10 000 tonnes in 1992, 2004, 2010 and 2012, presumably following relatively strong recruitment events.However, there has been increased emphasis on alfonsino, warty oreo and mirror dories, while gillnetting and longlining have risen in importance relative to trawling (Uchida and Tagami, 1984; Belyaev and Darnitskiy, 2005; Clark *et al*., 2007; Dionne, 2016; Kiyota *et al*., 2016; plus information provided by the NPFC Secretariat).

Crabs

There was a brief Russian pot fishery when 1–2 vessels fished for tanner, red and king crabs during 2002–2003,[7] which followed earlier Japanese explorations in 1977. The Russian fishery worked on Showa, Yomei, Nintoku and Koko seamounts (Russia, 2008; NOAA, 2008). Bycatches of unidentified spider crabs were also reported (Figure 11.9).

Red coral

Beginning around 1965 and continuing for about ten years, Koko, Yuryaku and Kammu seamounts also saw some Japanese and Korean fishing for red coral: specifically *Corallium secundum*, at 400–450 m depth, using primarily tanglenet dredges (Figure 11.5c), which landed a record 375 tonnes. As many as 100 vessels are said to have operated in the fishery that year. A deeper fishery (1 000–1 500 m) for *Coralium* sp. nov. began in about 1978 and ended around 1992. Catches reached 300 tonnes in 1981, when 17 Japanese and 100 Korean vessels were involved, each of about 100 GRT. Over the history of the fishery, the Japanese fleet took approximately 2 000 tonnes of coral, half of it during the first three years (Clark *et al*., 2007; FAJ, 2008c; NOAA, 2008).

Northeast Pacific seamounts - sablefish and rockfish

From 1978, there was limited fishing on Cobb and Warwick seamounts (in the high seas, southwest of Vancouver Island), primarily by Japanese vessels, with total catches of a few thousand tonnes composed mostly of rockfish (Clark *et al*., 2007). A longer-lasting fishery involving Canadian vessels has targeted sablefish, a species that has been fished commercially along the Pacific coast of Canada since the nineteenth century. The fishery expanded with the arrival of Japanese longliners in 1968, in addition to an increase in Canadian effort following the extension of national jurisdiction in 1977, and the successful development of longline hook and trapping techniques after 1973. The fishery has always operated primarily along the continental margin, where annual catches were around 4 000–5 000 tonnes for three decades; they have since fallen to around 2 000 tonnes annually. Since the 1980s there has also been some fishing on

[7] The catches of king crab were originally reported as 'snow' crab.

seamounts both in the high seas and national waters, though the recent average annual catch in the high seas has been around 20 tonnes, with that in national waters averaging 50 tonnes annually for the same period (Table 11.5). Almost all of this catch has been taken from Bowie Seamount, which lies within the Canadian EEZ towards its northern boundary. However, the area is now closed to bottom fishing following its declaration as a marine protected area (McFarlane and Beamish, 1983; DFO, 2013; Du Preez, 2018). Small quantities of sablefish have been taken by longline hook and traps from high seas seamounts, including Eickelberg, Warwick, Cobb and Brown Bear. A small number of fishing trips have also occurred to some seamounts in the Gulf of Alaska, including at Surveyor, Pratt, Durgin, Cowie, Murray, Miller and Pathfinder Seamounts (DFO, Canada, personal communication).

These small-scale seamount fisheries continue, though information is only available on the Canadian sablefish fishery. High seas seamount catches in the 2014–2018 period averaged 37 tonnes annually (DFO, Canada, personal communication). Minor target and bycatch species include Dover sole, Pacific Ocean perch, rougheye, blackspotted and canary rockfish, shortspine and longspine thornyhead, and skilfish. The vessels used average 24.9 m length (De Preez, 2018).

TABLE 11.5

Annual average sablefish landings (tonnes) on seamounts inside and outside the Canadian EEZ from all British Columbia fisheries during specified fishing periods

Period	Number of years	Inside EEZ	Outside EEZ
1980–1988	9	29	7
1989–1993	5	185	56
1994–1998	5	64	39
1999–2003	5	89	41
2004–2008	5	54	16
2009–2013	5	63	18
2014–2018	5	18	37

Source: DFO, Canada, pers. com.

Other seamount fisheries

It is likely that a number of seamount fisheries, operating in the EEZs of the North Pacific occasionally harvest small quantities of fish from locations more than 200 nautical miles from land. The same is known to occur in the Atlantic, where Azorean fishermen work seamounts south of the EEZ around their islands. Some of the East Pacific Rise seamounts in the high seas are known to be fished for large pelagic species. Bensch *et al.* (2009) noted anecdotal reports of a deep longline fishery for morwong on seamounts under national jurisdiction in the southwestern portion of the region, suggesting that there might be similar fisheries in the high seas. They also mentioned some crab potting in 2006. Otherwise, the only reported examples of bottom fishing on high seas seamounts around the margins of the North Pacific come from the extreme northeast.

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12. South Pacific Ocean

FAO Major Fishing Area 81, most of Area 87, plus portions of Areas 57, 71 and 77

SUMMARY

The huge expanse of the high seas of the South Pacific Ocean is mostly far too deep to fish with bottom contact gears, though pelagic fisheries are abundant. Waters at fishable depths occur on the plateaus, ridges and slopes around Australia and New Zealand and in various seamount chains on the eastern and western sides. Highly targeted deepwater bottom trawl fishing known as "hill fishing", developed in the 1990s, opened up the exploitation of orange roughy stocks. This species, now much depleted, has formed the basis of the bottom fishing and continues to do so at much reduced levels. The bottom trawls also catch and occasionally target moras, oreos and cardinalfish. Alfonsino and pelagic boarfish, usually targeted separately, are typically fished just off-bottom with very deep-set midwater trawls that only occasionally touch the sea floor. Bottom-set longlines typically target emperors, hapuku and bluenose warehou, and is undertaken mainly by Australian vessels. Some deepwater dogfish have been taken in recent years by vessels from the European Union and New Zealand. New Zealand operates a small toothfish fishery.

Historical catches taken within the current high seas area are difficult to estimate owing to joint-venture arrangements within New Zealand EEZs in the 1980s involving the former USSR/Russian Federation and other fleets. Certainly, most of the catches have been taken within EEZs and may have reached 50 000 tonnes in the 1980s. However, the high sea catches have been estimated as reaching 17 300 tonnes, mainly by Russian vessels (SPRFMO, 2019). High sea catches in 2016 were estimated at 1 510 tonnes, taken mostly by bottom trawling, 60 percent of which was orange roughy (Table 12.1).

TABLE 12.1
High seas bottom fisheries catch in the South Pacific for 2016 (including deep midwater trawl).[1]

Gear	Ground	Flag states	Species	Catch *(tonnes)*
Bottom trawl	Tasman Sea, Louisville rise	New Zealand, Australia	orange roughy	915
Bottom trawl	Tasman Sea, Louisville rise	New Zealand, Australia	cardinalfishes, oreo dories	36
Bottom line	Tasman Sea	New Zealand, Australia	emperors, hapuka, bluenose warehou, amberjacks, snappers morwongs	227
Bottom line	Pacific-Antarctic Rise	New Zealand	Antarctic toothfish	28
Midwater trawl[1]	Tasman Sea, Louisville rise	New Zealand, Australia	alfonsinos	169
various	various	New Zealand, Australia, European Union (Member Organization)	grenadiers, moras, groupers, dogfish sharks, pelagic armourhead, scorpion fish, sharks and rays, slimeheads, other mixed species	135
TOTAL				1 510

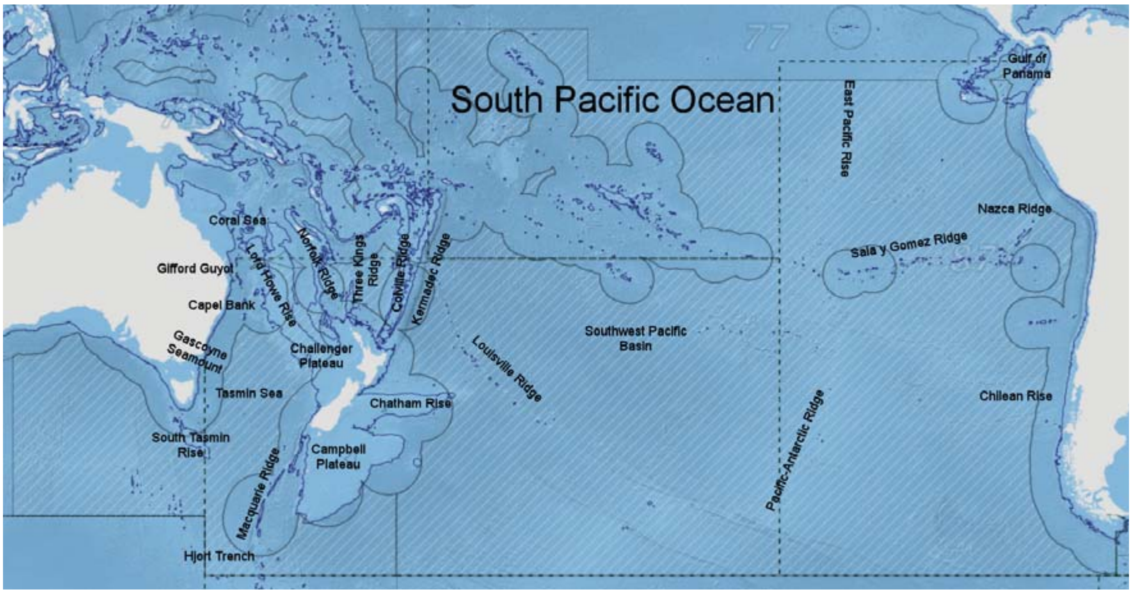
[1] The deep midwater trawl fishery does not involve bottom-contact fishing. It is included here because, with currently available data, its catches cannot be separated from those of the bottom trawl fishery (Tingley, 2014).

Source: SPRFMO, 2019.

GEOGRAPHICAL DESCRIPTION

For the purposes of this review the vast Pacific Ocean is divided, somewhat arbitrarily, on the 10° N parallel and the waters south of the Antarctic Convergence. The South Pacific region is by far the largest of the 11 recognized in this review: it is nearly twice as big as the North Pacific, the second-largest, and also has the most extensive high seas (Figure 12.1; Table 12.2).

FIGURE 12.1
Map of the South Pacific Ocean showing the SPRFMO convention area (shaded)



200 nautical mile arcs, 2 000 m isobath (GEBCO), FAO fishing areas.
Source: FAO VME Database, Mercator projection.

The continental shelf in the west varies from narrow to broad, much of it under national jurisdictions. The shelf on the eastern side is generally very narrow, except for the Gulf of Panama. Between these margins the Pacific is mainly deep ocean far beyond the reach of bottom fisheries. It is traversed by various ridges and dotted by seamounts, many of which rise above the surface as islands, particularly in the western and central portions of the region but including some in the east. There are also some larger islands in Melanesia that are not, in origin, seamounts.

The EEZs around the various coasts and islands break the South Pacific high seas into multiple parts. The greatest expanse lies east of New Zealand and west of Chile. There is a matching tropical area between Polynesia and the Americas, with the EEZs around Pitcairn, Easter Island/Rapanui and *Las Islas de los Desventurados* largely separating those two broad swaths of high seas. In the southwest, there is a third extensive area of high seas in the Tasman Sea and south of Australia, while the northwestern quadrant of the region has multiple high seas enclaves, including one due north of New Zealand that has seen some bottom fishing. Most of the continental shelf around New Zealand is within the EEZs of New Zealand, Australia and France.

Within the region's high seas, the principal seabed features at potentially fishable depths are: the South Tasman Rise (which straddles the boundary of the Australian EEZ, south of Tasmania); those parts of Challenger Plateau, Lord Howe Rise and West Norfolk Ridge which lie outside any EEZ; Three Kings Ridge and the paired Kermadec and Colville Ridges (north of New Zealand's main islands and largely within EEZs); Louisville Ridge (east of New Zealand's EEZ) and Geracl Ridge (far to the southeast). There are two very small enclaves entirely surrounded by New Zealand's EEZ and lying east of South Island. Both of these overlie productive fishing grounds and are fished by New Zealand vessels, but there does not appear to have been any distant-water fishing in either since the EEZ was declared in 1978.

In the eastern South Pacific, the Sala-y-Gomez Ridge stretches from near the Chilean coast west to Easter Island/Rapanui, with the Nazca Ridge nearby. Finally, the global mid-ocean ridge network includes a spreading centre, the Pacific-Antarctic Ridge, which runs along much of the region's southern boundary: that ridge curves northwards near the 110° W meridian, where it is named the East Pacific Rise. Most of that very extensive feature is too deep for fishing though it is dotted with seamounts and is shallower near the region's northern boundary, where it also breaks the surface as *Île de Clipperton*. Overall, the South Pacific high seas contain a considerable extent of seabed shallower than 2 000 m relative to the other ocean regions but very little above 400 m depth (Table 12.2).

TABLE 12.2
Area statistics for the South Pacific Ocean

Geographical area	Surface area (km²)
Total sea area	113 794 000
Area of high seas	64 614 000
Area of high seas shallower than 200 m	4 000
Area of high seas shallower than 400 m	10 000
Area of high seas shallower than 1 000 m	112 000
Area of high seas shallower than 2 000 m	648 000

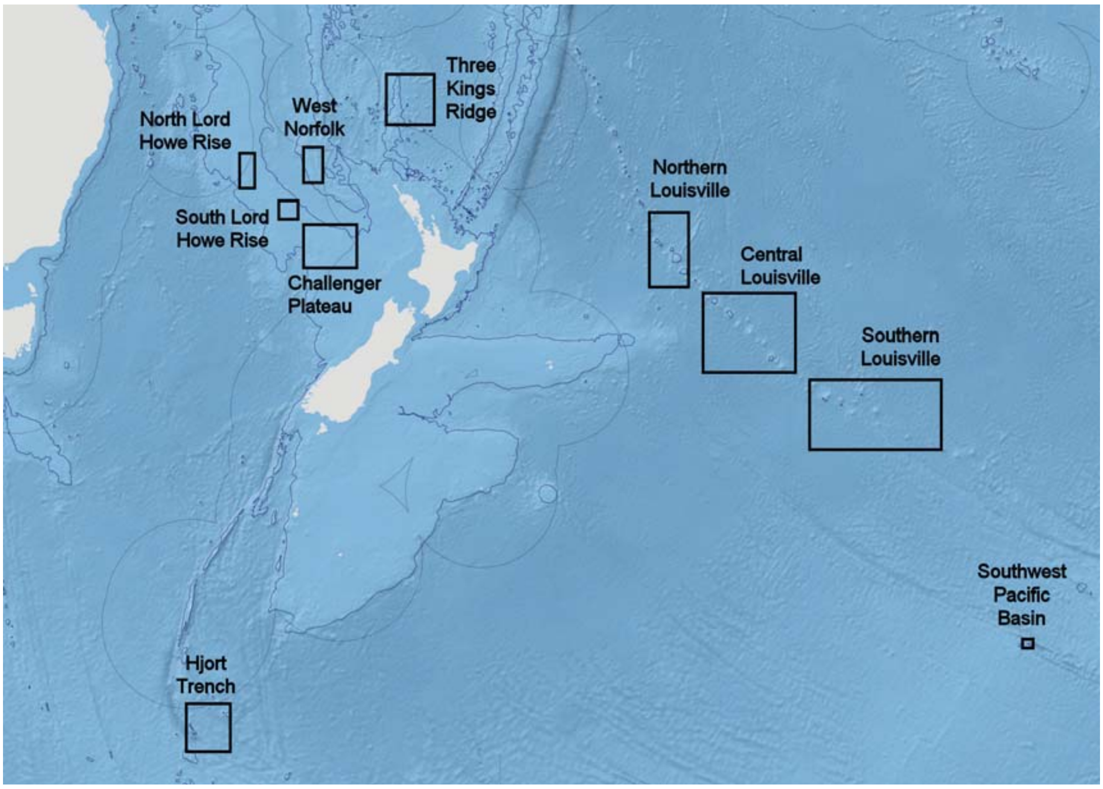
ECOSYSTEMS AND RESOURCE SPECIES

The oceanography of the South Pacific, like the North Pacific, is dominated by an enormous subtropical anticlockwise gyre. In the east, the north-flowing Humboldt Current shapes the most productive upwelling ecosystem on the world's eastern boundary. The Humboldt Current supplies water to the South Equatorial Current that flows westward and is distributed in multiple directions as it approaches the many islands on the west side of the Pacific. The less prominent East Australian Current flows generally southwards towards Antarctica and joins the east-flowing Antarctic Circumpolar Current or West Wind Drift, which encircles the globe.

The region's major fishery resources fall within EEZs. Pelagic species include the Peruvian anchoveta, various tunas, jack mackerel, jumbo flying squid and others. As in all ocean basins, the principal demersal resources are found on continental shelves and slopes in temperate latitudes – though the only land mass in the region's cold–temperate zone is southern Chile, which has a very narrow continental shelf; the only extensive area of temperate shelf comprises the deep-lying plateau around New Zealand. The region's demersal resources are therefore not highly productive by global standards. On the South American margin there is substantial production of hoki, southern blue whiting, south Pacific hake and southern hake. Annual catches of hoki exceeded 350 000 tonnes in a few years of the 1990s and the hakes have sometimes yielded similar amounts, though all are currently depleted (Aguayo-Hernández, 1995; Espino *et al*., 1995; Alarcón and Arancibia, 2015; Gatica *et al*., 2015). Hoki is also important off New Zealand, where annual catches amounted to about 250 000 tonnes in the 1990s (Livingston *et al*., 2015), and the resource also supports a smaller fishery around the southernmost parts of Australia. Southern hake catches in the west, which occurs almost entirely in waters under New Zealand's jurisdiction, is an order of magnitude smaller compared to catches of its eastern congeners and conspecifics (Horn, 2015). Southern blue whiting yielded a peak catch of 76 000 tonnes from New Zealand waters in 1991–1992 (Cole *et al*., 2013). None of those demersal species are fished in the high seas of the South Pacific but they do support national fisheries in the areas where two of the three late developments in high seas bottom fishing began: orange roughy trawling off New Zealand, and deep longlining for adult Patagonian toothfish in Chilean waters. Moreover, small numbers of Patagonian toothfish occur within both Australia and New Zealand's EEZs, on the Macquarie Ridge and as far north as the Campbell Plateau, where there have been small fisheries (Collins *et al.,* 2010; MfPI, 2013). Further details of the resources species are available on the SPRFMO website.[1]

The lack of fishable seabed in the South Pacific high seas necessarily imposes severe limitations on the production of exploitable resources in those waters. A map showing the major locations of high seas bottom fishing locations in the western South Pacific is provided in Figure 12.2. Orange roughy have been found in exploitable concentrations only on the plateau, ridges and rises from the South Tasman Rise to the Louisville Ridge. In addition, various other species, including alfonsino, hapuku and bluenose warehou, can be viably exploited by longliners. Antarctic toothfish are found on some high seas seamounts in the vicinity of the Antarctic Convergence, including on the Pacific-Antarctic Ridge within the southernmost waters of the South Pacific region (Figure 12.3).

FIGURE 12.2
SPRFMO general bottom fishing areas in the western South Pacific Ocean



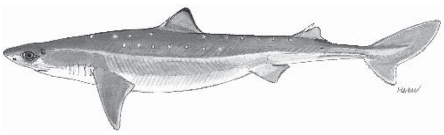
Source: Information from NABIS, Ministry for Primary Industries, New Zealand https://maps.mpi.govt.nz/templates/MPIViewer/?appid=96f54e1918554ebbaf17f965f0d961e1; FAO VME Database.

[1] www.sprfmo.int/science/species-profiles/

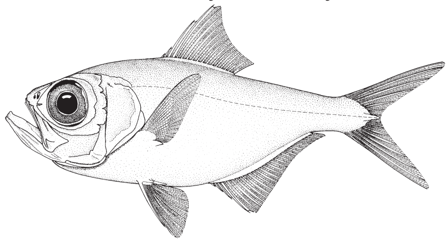
FIGURE 12.3

Principal demersal resource species of the high seas of the South Pacific Ocean

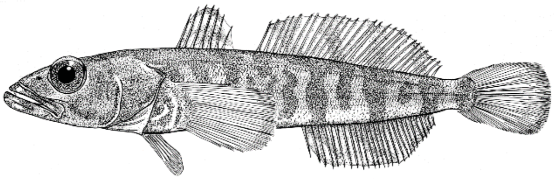
picked dogfish *Squalus acanthias*[1]



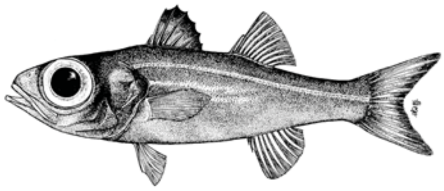
alfonsino *Beryx decadactylus*[1]



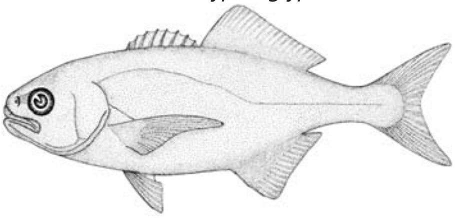
Antarctic toothfish *Dissostichus mawsoni*[1]



black cardinalfish *Epigonus telescopus*[1]

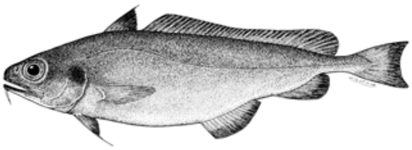


bluenose warehou *Hyperoglyphe Antarctica*[1]

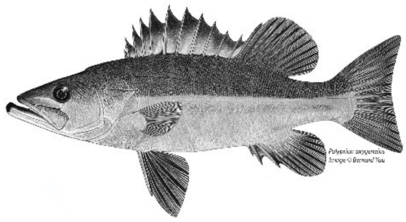


blue (Patagonian) grenadier "hoki" *Macruronus novaezelandiae*[1]

common mora "ribaldo" *Mora moro*[1]

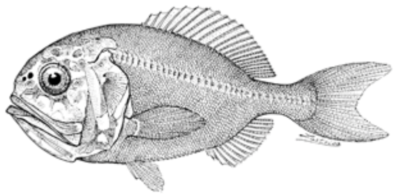


hapuku *Polyprion oxygeneios*[2]

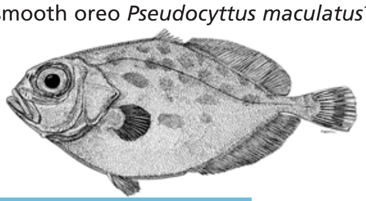


jackass morwong *Nemadactylus macropterus*[3]

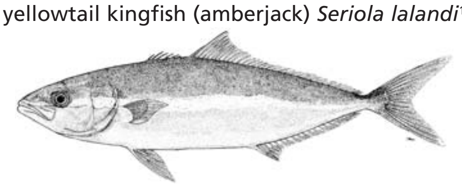
orange roughy *Hoplostethus atlanticus*[1]



smooth oreo *Pseudocyttus maculatus*[1]



yellowtail kingfish (amberjack) *Seriola lalandi*[1]



Source:

[1] Food and Agriculture Organization of the United Nations, Original Scientific Illustrations Archive.

[2] NSW (2010), reproduced with the permission of the artist Bernard Yau.

[3] Waite (1921).

MANAGEMENT OF HIGH SEAS BOTTOM FISHERIES

Conservation and management of orange roughy on the South Tasman Rise

The South Tasman Rise is a plateau that straddles the boundary of Australia's EEZ, and features a number of minor seamounts. Orange roughy are present on the plateau's surface but it does not support any rich resources. In 1997, after the specialized techniques of "hill fishing" had been developed, aggregations of roughy were found on the seamounts. High seas catches rose quickly, initially taken by Australian and New Zealand vessels, exceeding 4 000 tonnes in 1998–1999. Australia claimed management authority over what it saw as a straddling stock and, in 1998, entered into a Memorandum of Understanding with New Zealand, which provided for separate national TACs – thus initiating bilateral management of bottom-contact fisheries in the South Pacific high seas. The initial MoU was not renewed in 1999 but a new one – the Arrangements between the Government of Australia and the Government of New Zealand for the Conservation and Management of Orange Roughy on the South Tasman Rise – was adopted with effect from March 2000. In that year, however, the fleet was only able to find enough roughy to land 830 tonnes; thereafter the catch dwindled further, dropping to 110 tonnes in the 2002–2003 season (Molenaar, 2001; Annala and Clark, 2005; Serdy, 2005). The fishery was closed, by bilateral agreement for the 2007–2008 season and has not been reopened since.[2]

South Pacific Regional Fisheries Management Organization (SPRFMO)

SPRFMO was the first organization to manage the non-highly migratory fisheries of the South Pacific high seas. It entered into force in 2012 following ratification of the Convention on the Conservation and Management of High Seas Resources in the South Pacific Ocean. The current membership includes: Australia, Chile, China, Cook Islands, Cuba, Ecuador, the European Union, Denmark (in respect of the Faroe Islands), the Republic of Korea, New Zealand, Peru, Russian Federation, Taiwan Province of China, United States of America and Vanuatu; Curaçao, Colombia, Liberia and Panama are cooperating non-contracting parties.[3] An interim SPRFMO Science Working Group and a Data and Information Working Group was established in 2006, during the first international consultation, and it began work on the foundations of future management actions. From 2008 there were also more specialized jack mackerel and deepwater sub-groups. All continued their work until 2012, after which the SPRFMO Scientific Committee was formed, with its jack mackerel and deepwater (and later) squid working groups. SPRFMO also formed a Compliance and Technical Committee at that time.

The convention's objective is to ensure the long-term conservation and sustainable use of fishery resources through the application of the precautionary approach and an ecosystem approach to fisheries management, and thereby to safeguard the marine ecosystems in which these resources occur. The SPRFMO convention area is limited to the high seas and has an area of approximately 49 920 000 km^2 (Figure 12.1), which encompasses about a quarter of the world's high seas. SPRFMO competence covers all living resources except marine mammals, reptiles and birds, benthic species subject to the national jurisdiction of coastal states, diadromous fish, and highly migratory species.

To date, SPRFMO has been concerned with three very different types of fishing: bottom fishing in the southwestern parts of its convention area, pelagic fishing for jack mackerel, and jig fishing for jumbo flying squid in the east. Only the former is considered in this review. Interim management measures were adopted before the convention entered into force, some as early as 2007. These called on flag states,

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2 Information provided by the Australian Fisheries Management Agency.

3 Belize acceded to the Convention in 2011 but withdrew from membership in 2016. Columbia signed the convention but has not ratified it.

inter alia, to: limit bottom fisheries to existing levels of catch, fishing effort, capacity and vessel numbers, as well as to existing fishing areas (meaning those fished in 2002–2006); to establish management measures to prevent significant adverse impacts on vulnerable marine ecosystems (VMEs); and to ensure the long-term sustainability of demersal resources. From 2010, participants in the negotiation process committed to banning bottom-set gillnets. With the establishment of SPRFMO, formal conservation measures were introduced from 2013. They have developed into a comprehensive set of management tools, with protections for VMEs and seabirds, and the beginnings of conservation management of targeted benthic resources (Table 12.3). However, much of the implementation is still left to flag states, under the broad standards set by SPRFMO.

By 2018, Australia, New Zealand and the European Union had submitted impact assessments, and Australia and New Zealand had submitted maps of their bottom fishing activities (Figure 12.4). New Zealand's spatial-management measures include closing some areas within their existing fishing areas.

The SPRFMO Scientific Committee's work relating to the bottom fisheries in the southwest of the region has been largely concerned with the identification and protection of VMEs, including standards for impact assessments and predictive modeling, and the development of stock-assessment approaches for data-deficient deep-living resources such as orange roughy. The committee is supported by the scientific capabilities of the adjacent coastal states, which have larger fisheries for the same principal species within their EEZs and hence experience similar challenges at the national level.

TABLE 12.3
SPRFMO Conservation and Management Measures (CMM) applicable to bottom fisheries

Measure	Current CMM	Previous CMMs	Originally introduced
Data reporting standards	02-2018	02-2107, 1.03, 2.02, 3.02, 4.02	2013
Bottom fisheries, observer coverage, effort restrictions, assessment	03-2018	03-2017, 4.03, 2.03	2014
IUU vessel list[1]	04-2017	4.04, 1.04	2013
List of authorized vessels	05-2016	4.05, 2.05	2014
VMS	06-2018	06-2017, 2.06	2014
Port inspections	07-2017	2.07	2014
Bottom-set gillnets and trammel nets	08-2013	1.02	2013
Minimize seabird mortality	09-2017	4.09, 2.04	2014
Compliance and monitoring scheme	10-2018	10-2017, 4.10, 3.03	2015
Boarding and inspection procedures	11-2015	3.04	2015
Transshipment	12-2018	12-2017, 3.05	2016
New and exploratory fisheries	13-2016	4.13	2016
Lobster and crab (pot)	14b-2018		2018
Toothfish (bottom longline)		4.14	2016
Stateless vessels	15-2016	4.15	2016
Observer programme	16-2018		2018

[1] As of October 2018, the SPRFMO IUU vessel list contained three vessels.
Source: www.sprfmo.int/measures/

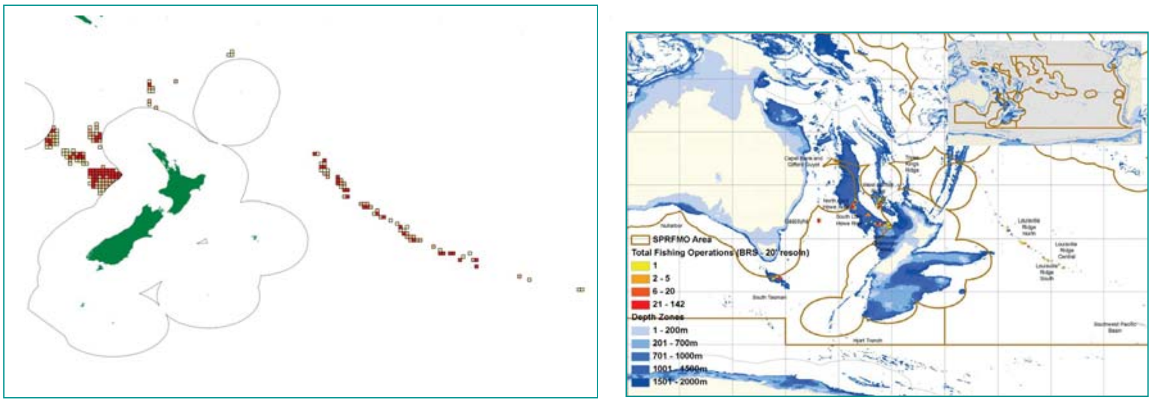
High seas in the equatorial Pacific

East of 150° W and north of 2° N the high seas are outside the convention area of either SPRFMO or NPFC. Thus far they lack an RFMO/A with competence over bottom fisheries. However, no such fisheries are known within the area and no major ones are expected, given the lack of similar fishing in low latitudes elsewhere.

Far to the west, another four North Pacific high seas enclaves east of the Philippines extend above the 10° N regional boundary which defines the SPRFMO Area. However, given that they extend beyond the SPRFMO remit in near-equatorial latitudes, west of

FIGURE 12.4

Historical bottom fishing footprints for: (a) New Zealand for bottom trawling, and (b) Australia for all gears combined, based on activities in 2002–2006 in the SPRFMO convention area



(a)

Red = heavily fished (> 9 tows), Orange = moderately fished (3–9 tows), Yellow = lightly fished (< 3 tows).
Source: MoF, 2008; www.nabis.govt.nz/map.aspx; seen Feb 2019.

(b)

Source: Williams *et al*., 2011, Figure 3.1.2.1

the 135° E limit, there is no reason to suppose that any bottom fishing occurs in that limited area.

DESCRIPTION OF HIGH SEAS BOTTOM FISHERIES

Bottom trawl

Early years: 1940s–1970s

The high seas bottom fisheries of the South Pacific came about as separate but interacting, developments in the east and the west of the region. Chilean fishermen commenced trawling for hake in what is now their national EEZ in the 1940s, the fishery growing and expanding over the decades, both geographically and across species (Aguayo-Hernández, 1995; Espino *et al*., 1995; Alarcón and Arancibia, 2015; Gatica *et al*., 2015). In the 1950s, Chilean hake trawlers discovered a resource of galatheid squat lobsters on the upper continental slope, at the depth of the pronounced oxygen minimum layer seen in the eastern central Pacific.[4] A directed fishery developed and has continued (Wehrtmann and Acuña, 2011). A few years later, similar bycatches in hake trawls led to a fishery for nylon shrimp at depths down to 500 m, which reached peak landings of 72 000 tonnes in 1976 (Wehrtmann *et al*., 2012). Deep trawling was thereby introduced to the region.

Expansion in the 1980s

Meanwhile, the global expansion of distant-water fisheries that had been unleashed by development of the factory-freezer stern trawler reached the South Pacific, though it was the last of all the major ocean basins to be exploited in this manner. During the 1970s and even into the 1980s, vessels from the former USSR and other members of the former ‘Eastern Bloc’ group, as well as from Japan, explored the ridges and other features in what are now the South Pacific high seas. In the east, the areas explored included the Sala-y-Gomez and Nazca ridges and the East Pacific and Chilean rises; in the west, the South Tasman and Lord Howe Rises, the Norfolk, Kermadec and Colville Ridges, as well as Macquarie Ridge in the south, plus the Chatham Rise and Louisville and Geracl Ridges to the east were all explored. Catches where seamounts rose above

[4] Referred to as “langostino” in the seafood trade: primarily blue squat lobster and carrot squat lobster.

250 m depth included pink maomao, cardinalfish, alfonsino, southern blue whiting and various macrourid grenadiers (Kenchington and Dews, 1986; Pavlov and Andrianov, 1987; Clark *et al.,* 2007), though the presence of small, dense aggregations of orange roughy was not then known. Little was found in the areas which are now the high seas; the only moderately significant commercial fishery to emerge during that era worked the Geracl Ridge in 1972 and 1973, taking 8 800 tonnes of cardinalfish the first year but little thereafter (Clark *et al.*, 2007).

Targeting orange roughy

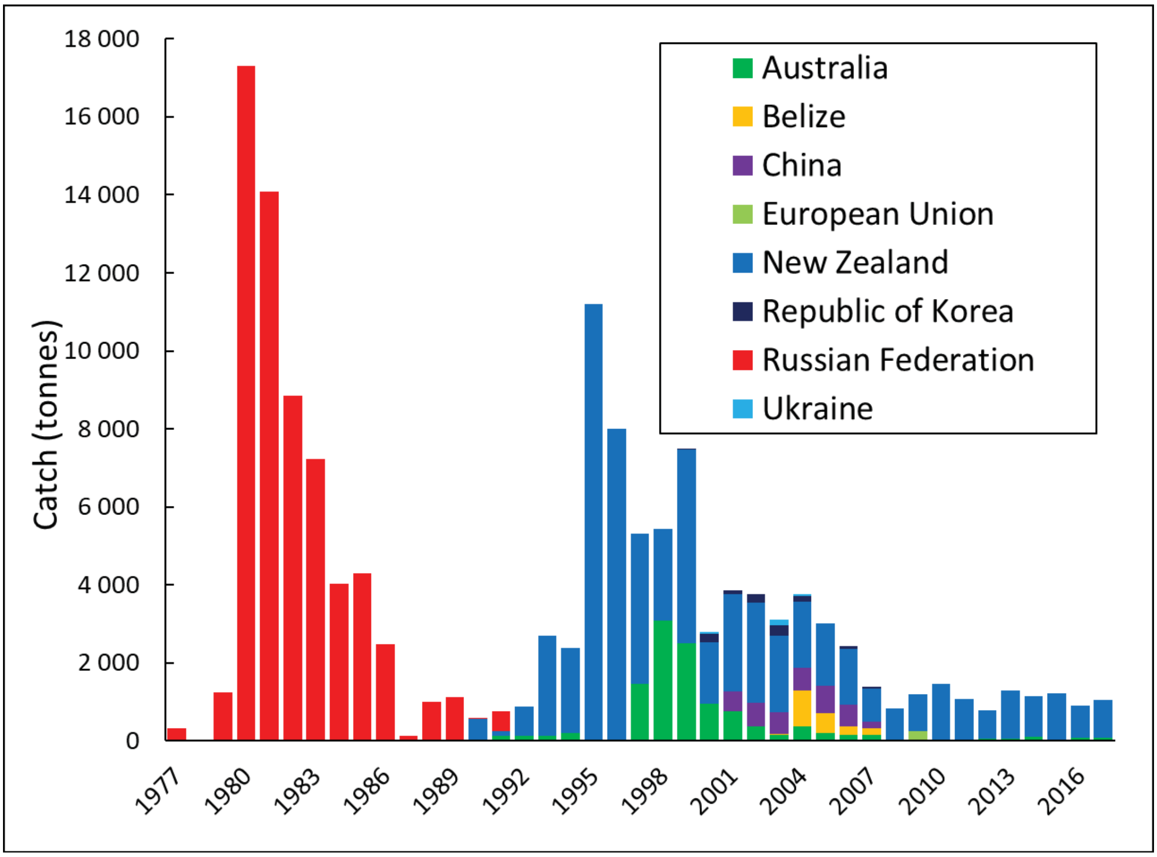
Economic pressures on New Zealand during the 1970s encouraged the development of an offshore fishery, which necessarily worked the deep grounds in the country's newly established EEZ. The first large fishery was for hoki, though there has also been fishing for southern hake and southern blue whiting. Fishermen discovered that orange roughy, which had been a mere taxonomic curiosity previously, form small but very dense aggregations that could be exploited on the relatively smooth seabed of the Chatham Rise. A directed fishery emerged from 1979. Local catch rates fell swiftly (as expected when such a virgin resource is first exploited) and the fleet responded by expanding into new areas within the New Zealand EEZ, with annual catches rising to about 50 000 tonnes by the mid-1980s (Clark, 1995; Branch, 2001).[5] Increasing skill and technological development, particularly high-powered echo sounders with sensitive colour displays and the Global Positioning System (GPS – fully functional from 1993), allowed the development of techniques for "hill fishing" on seamounts, knolls and other bathymetric features, resulting in the fishery's expansion into areas that were previously inaccessible. Across the Tasman Sea Australian fishermen had developed continental-slope trawling for gemfish during the 1970s (Tull and Polacheck, 2001). In the early 1980s New Zealand's success encouraged national fisheries for hoki (known in Australia as "blue grenadier") and from 1986 for orange roughy (Bax *et al*., 2005).

The general spatial expansion of the roughy fisheries, including the increasing ability to work more difficult grounds, took New Zealand trawlers onto Lord Howe Rise and the high seas portion of the Challenger Plateau from 1987. Vessels under the flags of Australia, Japan, the Republic of Korea and Russian Federation joined in, raising the high seas catch to 4 000 tonnes in the first full season and more in 1992–1993 but the fishery declined from there. By the turn of the century, only a few hundred tonnes were taken annually from Lord Howe Rise and 1 000 tonnes or more from the plateau – all of it by New Zealand and Australian trawlers. From the 1993–1994 season, trawlers from those same two flag states then began working the Louisville Ridge, taking more than 13 000 tonnes in the second season; however, by 1996–1997 annual catches were down to a few thousand tonnes. As noted above, in 1997, the Australian fleet began working the small seamounts on the high seas portion of the South Tasman Rise, followed soon after by New Zealand trawlers. Catches of 3 900 tonnes were taken in 1997–1998 and over 4 000 tonnes the following year. In June 1999, three vessels from South Africa and one from Belize entered the fishery, though they were soon withdrawn in response to Australian requests to their flag states. The high seas catch from that area fell nonetheless, dropping to 830 tonnes in 2000–2001 and 170 tonnes the following year. Meanwhile, New Zealand fishermen began working the high seas portion of the West Norfolk Ridge from 2000. Together with the Australian fleet they took almost 700 tonnes the following year but catches then dropped to a low level.

[5] In the early years of the orange roughy fishery, New Zealand utilized foreign-flag vessels, some from the former USSR, operating under Joint Venture arrangements, before its own fleet had grown sufficiently. Catches by former USSR vessels were reported to FAO by flag state, potentially giving rise to a misunderstanding that there was a considerable roughy fishery in the high seas of the southwest Pacific during the early 1980s when it was actually within the EEZ.

Taken as whole, across the various grounds, New Zealand's high seas orange roughy catch peaked at 11 200 tonnes in 1995, falling to below 4 000 tonnes by 1997. Australia's catch surpassed 3 000 tonnes in 1998, but aside from the high years of the South Tasman Rise fishery (1997–2001) it has been amounted a few hundred tonnes per year. Trawlers under the flags of Belize, China, Cook Islands, the Republic of Korea, Japan, Norway, Panama, Russian Federation, South Africa and Ukraine were all involved in the southwest Pacific orange roughy fisheries at one time or another. However, the reported catches by all of those fleets combined never reached 2 000 tonnes in any one year. By the turn of the century, non-NZ and non-Australian catches were under 1 000 tonnes and declined to nothing in 2008 (Clark, 1990; Branch, 2001; Molenaar, 2001; Gianni, 2004; Annala and Clark, 2005; Clark *et al.*, 2007; SPRFMO, 2019). As late as 2006 there were two trawlers fishing under the flag of Cook Islands and two others under that of Belize (Bensch *et al.*, 2009) but none of them fished in the South Pacific high seas after 2007. Only New Zealand, and to a lesser extent Australia, have continuously worked the fishery since 1990 (Figure 12.5).

FIGURE 12.5
Catches of orange roughy in the high seas of the South Pacific



Source: SPRFMO, 2019.

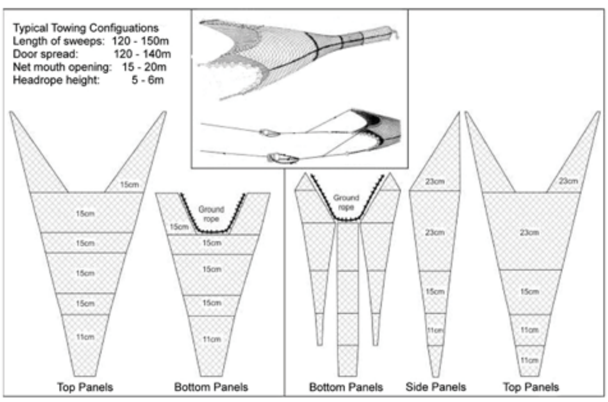
Seamounts and orange roughy

New Zealand's success in fishing orange roughy led others to explore its potential. In time, commercial fisheries emerged in the northeast Atlantic, southeast Atlantic and Indian Ocean, in addition to the South Pacific. Chilean fishermen were involved in the global roughy exploration and first found commercially viable aggregations off their coast during 1997–1998. Subsequent surveys found them on only a few seamounts between Juan Fernandez and the mainland, at about 33° S latitude; a small fishery developed but landed less than 2 000 tonnes per year through to 2003 (Payá *et al.*, 2005; Anon., 2008). All of the seamounts with viable roughy aggregations lie within waters under national jurisdiction. A Chilean fleet of 18 vessels also fished for alfonsino, including (apparently) in the EEZ around *Las Islas de los Desventurados* (about 26° S, near the junction of the Nazca and Sala-y-Gomez ridges). In 1998 and again during 2001–2005 small catches were taken from the high seas; from 2002 onwards (but potentially in previous years as well) the fishing occurred immediately outside the Chilean EEZ, west of the islands (Anon., 2008). The only other known high seas bottom fishing in the east of the region was a Chilean exploratory fishery for lobster on the Nazca Ridge in the early 1990s (Bensch *et al.*, 2009).

New Zealand trawl fisheries in the 2000s

The New Zealand high seas bottom trawl fishery primarily uses aimed trawling, with minimum bottom contact, whether targeting orange roughy, alfonsino, cardinalfish or oreo dories. During 2002–2006, about half the tows were on bottom for no more than 0.5 hours, with a modal length of 2 nautical miles (3.7 km); many were in contact with the seabed across much shorter tracks, though some tows were recorded as extending over as much as 10 hours and 55 km. In 2008, the typical nets were bottom trawls with wingspreads of 15–20 m, headline heights of 5–6 m and relatively short sweeps and bridles, for door spreads of 120–150 m. The gear was optimized for control, rather than for herding fish during long tows (Figure 12.6). The ground gear was originally bobbins but rockhoppers began to be used more often, while the otter doors had changed from low-aspect "V" designs, which required bottom contact for full effectiveness, to high-aspect versions, effective in midwater. The nets were fitted with a suite of acoustic sensors for wingspread, headline depth, height off bottom and net positioning. Under normal operation, the ground gear only touched bottom under the targeted aggregation, while the doors remained off-bottom throughout. The trawlers active in 2008 were not large: 33–44 m in length, 300–700 GRT, with main engines of 700–1 600 kW. They were, however, well equipped with electronic instruments. High power (10 kW) and low frequency (28 kHz) sounders, with ceramic transducers and advanced signal-processing software, provided indications of fish at great depths, while GPS provided high-precision positions. Scanning sonar, to track fish in three dimensions, was common. Self-tensioning trawl winches were universal. Critically, the fishing captains had accumulated personal experience and skill in the demanding tasks of targeted trawling at great depth (MoF, 2008).

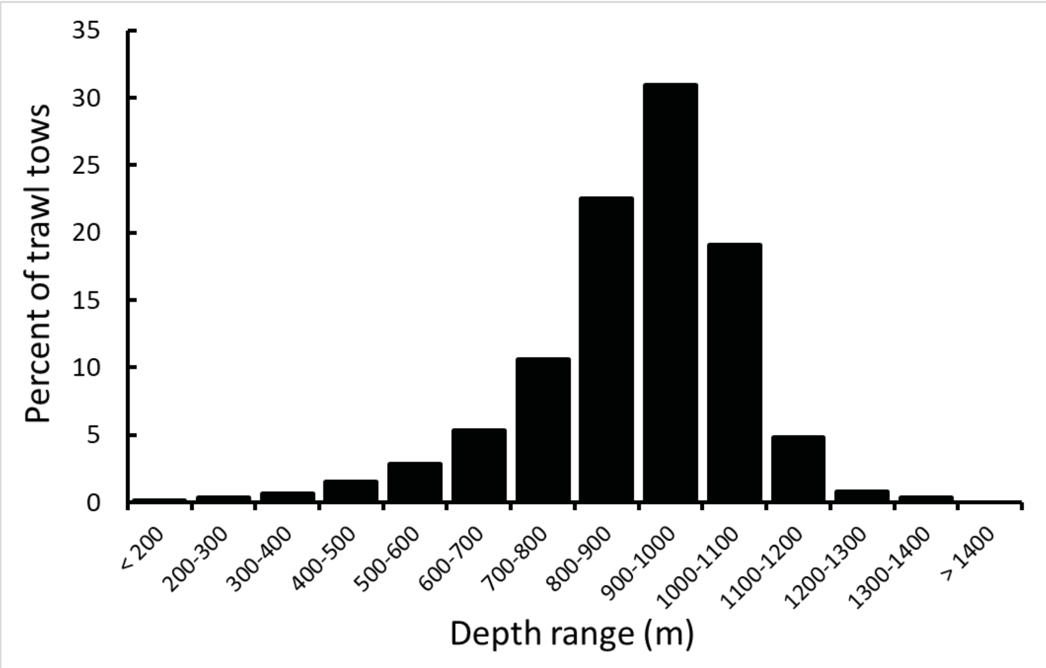
FIGURE 12.6
Configuration of a typical bottom trawl net during trawling in the targeted New Zealand deepwater orange roughy bottom trawl fishery



Typical towing configurations: length of sweeps 120–150 m, door spread 120–140 m, net mouth opening 15–20 m, headrope height 5–6 m
Source: MoF, 2008.

As many as 55 trawlers fished in 1996 but that number steadily declined and just nine fished in 2007. The number of tows also fell, from 2 944 in 2002 to 1 135 in 2006. During the same period, the high sea trawl fleet fished from near-surface depths down to below 1 300 m but 83 percent of the sets were at depths of 700–1 100 m, with a strong modal depth of 900–1 000 m (Figure 12.7). It was a winter fishery, conducted from April to August. The catch was 78 percent orange roughy, while another 10 percent was evenly divided between black oreo and black cardinalfish. The remainder of the catch was a mixture of alfonsinos (which grew in importance after 2009), smooth oreo, common mora (locally known as "ribaldo"), macrourid grenadiers and others. The grounds fished during 2002–2006, which have since become the fleet's "footprint", included long-established areas: Lord Howe Rise, West Norfolk Ridge, Challenger Plateau and Louisville Ridge, but also portions of the Three Kings and Colville ridges in the high seas. The relative importance of those grounds varied from year to year, with the West Norfolk Ridge yielding the most orange roughy in 2006 and 2007, whereas Louisville Ridge did for the previous three years and Challenger Plateau before that (MoF, 2008).

FIGURE 12.7
Depth distribution of New Zealand high seas trawl sets for 2002–2006 fishing in the SPRFMO area



Source: MoF, 2008.

Australian fisheries in the 2000s

The Australian fleet included 14 trawlers which fished on the high seas of the South Pacific between 2002 and 2007, with a maximum of nine working in any one year. However, numbers dropped to four in 2005 and to just two in 2007. Effort declined from 325 sets in 2002 to 206 five years later. The trawl fishery ceased entirely in 2008. High seas catches of orange roughy and other trawl-vulnerable species did not resume until 2011, when an alfonsino fishery began. However, landings of alfonsino peaked at just 167 tonnes the following year. By 2014 the primary target had become orange roughy, though national landings from the high seas amounted to only 102 tonnes, which dropped to 83 tonnes in 2016. There were also six line-fishing vessels, as many as five of them fishing in 2006. Most used autoline longline systems but two were dropliners and one used both gears. Catches fell to low levels in 2004 and 2005, when only the dropliners were active, but reported annual landings of 60–180 tonnes of unidentified fish have continued since then (Williams *et al*., 2011; SPRFMO, 2019), comprising both bycatches in the trawl fishery (in years when it operated) and the catches of the fixed-gear fleet.

During 2002–2007 in the region's high seas Australian trawlers used mostly bottom trawls but there was also some midwater trawling. The latter used a true pelagic trawl, albeit fitted with a sacrificial footrope in case of bottom contact, indicating that the fishing was sometimes close to the seabed, with the associated risk of damage. Longlines were set on the bottom or floated above it, with clip-on floats, depending on the species targeted. The droplines used were broadly similar to New Zealand Dahn lines (Williams *et al*., 2011).

The Australian fisheries' "footprint" – mapped in much the same way as its New Zealand equivalent – includes areas on the South Tasman Rise, Lord Howe Rise, Challenger Plateau, West Norfolk Ridge and Louisville Ridge (where there has been only limited Australian fishing effort).; many, though not all, of the 20' blocks are common to both states' "footprints". Additionally, Australian trawlers have fished on Gascoyne Seamount, in the high seas east of New South Wales, while dropline vessels have fished both there and on Capel Bank and Gifford Guyot – which lie close together in the Coral Sea (on the flank of Lord Howe Rise, in a narrow area of high seas between the EEZs around Lord Howe Island and the French islands of New Caledonia). Thus, most of the Australian high seas bottom fishing in the region involved only minor spatial extensions of fisheries in waters under national jurisdiction (Williams *et al*., 2011).

The bottom-trawl fishery made some sets at less than 200 m depth but largely worked below 700 m, and often below 1 000 m. Before it ceased in 2007, that fishery took primarily orange roughy, which accounted for the majority of the catch; in 2003 it took spikey oreo, with lesser amounts of alfonsino, smooth oreo and many others. Roughy and spikey oreo were mostly taken at 700–1 000m, whereas alfonsino was usually caught at 200–700 m depth, and smooth oreo at 1 000–1 500 m. Midwater trawls were mostly deployed at 200–700 m depth, largely over Lord Howe Rise; they took primarily alfonsino with some rudderfish, mixed boarfishes (Pentacerotidae), bluenose warehou ("blue-eye trevalla" in Australia) and others. Longlines were set at depths ranging from less than 200 m to a maximum of 1 500 m, though mostly above 700 m depth. The fishery targeted mainly redfinned emperor (mostly taken above 200 m) and yellowtail kingfish (taken both above and below 200 m), in addition to jackass morwong (usually 200–700 m), bluenose warehou (taken equally deep), sea bream (mostly above 200 m) and many others. All of the dropline effort was above 700 m depth; it took mostly bluenose warehou, bar rockcod and ocean blue eye trevalla, the proportions of which varied markedly from year to year (Williams *et al*., 2011).

No equivalent detail is available on Australian fishing in the South Pacific high seas after 2009, though it is known that catches have recovered to a few hundred tonnes each year (SPRFMO, 2019).

Longlines and gillnets

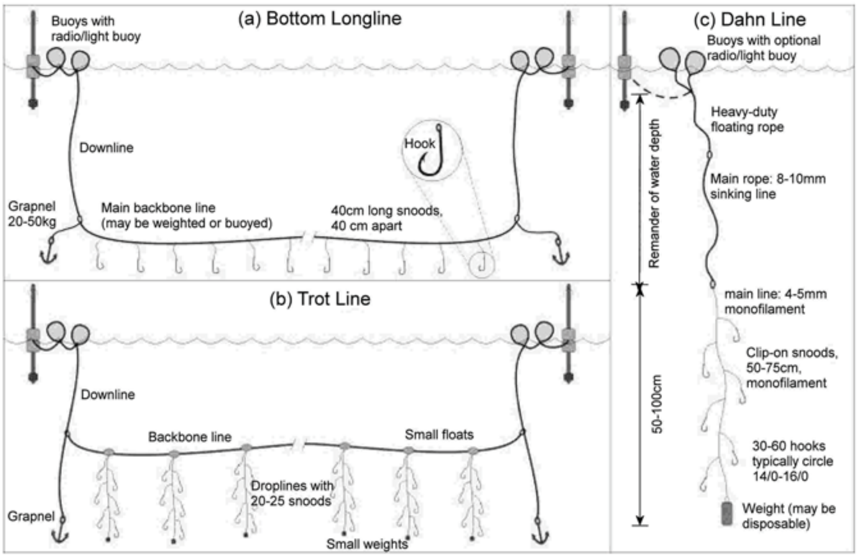
While most attention on the high seas bottom fisheries of the western South Pacific has been on trawling, fixed-gear fisheries also emerged there. Little is known of their early development, but New Zealand hook-and-line vessels were already active during the early 1990s, when one third of their effort was directed towards hapuku and most of the rest on bluenose warehou. Those fisheries have continued, though with a decreasing emphasis on hapuku (Mof, 2008). New Zealand high seas longlining had declined to zero effort by 2002 but subsequently rose to ten vessels, which made more than half a million hook-sets, in 2006 – an increase driven by rising prices for bluenose warehou. Effort dipped a little in 2007 but remained above the levels of earlier years (MoF, 2008).

The line-fishing fleet mostly uses bottom-set longlines, sometimes elevated above the seabed with weights and floats, generally equipped with circle hooks (Figure 12.8). During 2002–2006 most of the line fishing was at depths shallower than 700 m, with a modal depth of 400–600. However, 10 percent of the effort was at depths of 1 000–1 700 m (Figure 12.9). These fisheries were around the Pacific Antarctic Rise and Hjort Trench and conducted between October and April (the Austral summer), with peak catches in December. Nearly 70 percent of the catch was bluenose warehou, more than 20 percent hapuku and other wreckfishes, with smaller amounts of morwong, dogfish and a mix of other species. During those years, only 4 tonnes (< 0.5 percent) of Patagonian toothfish were reported. The grounds fished now form the fisheries' "footprint" (MfPI, 2015).

In 2015, New Zealand submitted a proposal to SPRFMO for exploratory longlining for toothfish in two areas near 60° S, between 142° W and 156°W, thus straddling the Pacific-Antarctic Rise, near the existing "Southwest Pacific Basin" area (MfPI, 2015). The work was undertaken in 2016 and 2017 under CMM 4.14 by an existing New Zealand toothfish longliner, on its return to port from the Ross Sea fishery (which falls under CCAMLR jurisdiction). The exploratory fishing provided useful information on the biology of Antarctic toothfish that has been shared with CCAMLR (SPRFMO, 2017).

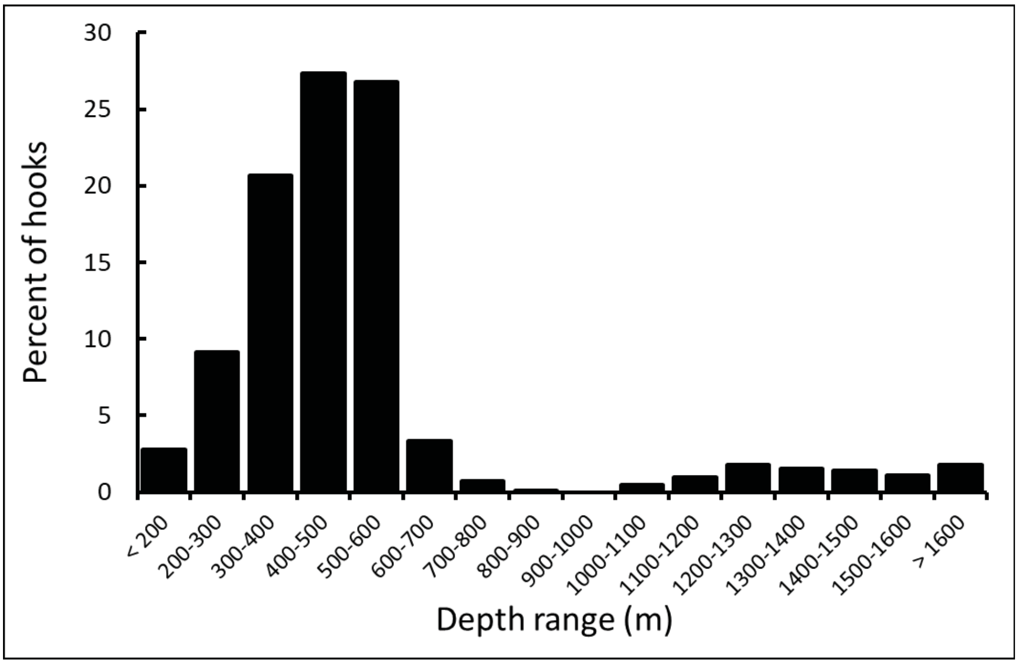
There was also an Australian gillnet fishery which included some high seas activity until 2003 (Williams *et al*., 2011). From 2008 until 2010, a Spanish gillnetter worked on the Challenger Plateau, Lord Howe Rise, East Norfolk Ridge and Three Kings Ridge (Anon., 2009), before such nets were banned by the SPRFMO CMM 1.02 in 2013. In 2006, there were also two vessels trapping for lobster in the high seas of the region, under the flag of Belize. They took 65 tonnes that year (Bensch *et al*., 2009).

FIGURE 12.8
Hooked longline gears used in New Zealand high seas fishery



Source: MoF, 2008.

FIGURE 12.9
Depth distribution of New Zealand high seas hook-and-line sets for 2002–2006 fishing in the SPRFMO area



Pots

The Cook Islands have received approval to undertake exploratory bottom fishing using pots to catch up to 1 000 tonnes of *Jasus* and *Projasus* lobster and *Chaceon* crabs annually, on no more than eight seamounts in the Foundation seamount chain between 2018–2021 (SPRFMO CMM 14b-2018).

Recent catches in the high seas

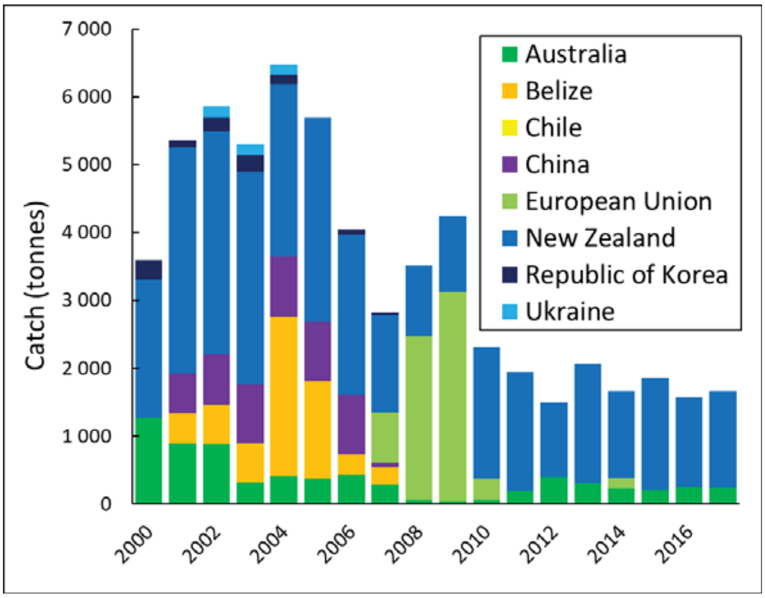
The SPRFMO Scientific Committee has compiled the available data on the high seas bottom fishery catches within its convention area from the best information available (SPRFMO, 2019). Catches recorded as unidentified or mixed species were included, as in most cases they come from demersal fisheries.

Orange roughy catches in the high seas have been reconstructed back to 1977 and show the large catches made by the Russian Federation in 1980–1982, of up to 17 300 tonnes annually. These declined rapidly to low values in the late 1980s, after which the Russian Federation left the fishery. Other countries, principally New Zealand and Australia joined the fishery in the early 1990s and, with technological improvements and the advent of "hill fishing", achieved high catches in areas that could not previously be fished, almost matching the success of the previous Russian fleets in terms of annual catches. However, the catches of both countries fell off at the turn of the century. Both have continued to exploit orange roughy in the high seas, but at much lower levels. Several other fleets briefly fished for orange roughy in the high seas, including Belize, China, the European Union, Republic of Korea and Ukraine, with peak annual catches in 100–700 tonnes range; however, these tended to be followed by low catches in the following year or two, leading to them leaving the fishery (Figure 12.5).

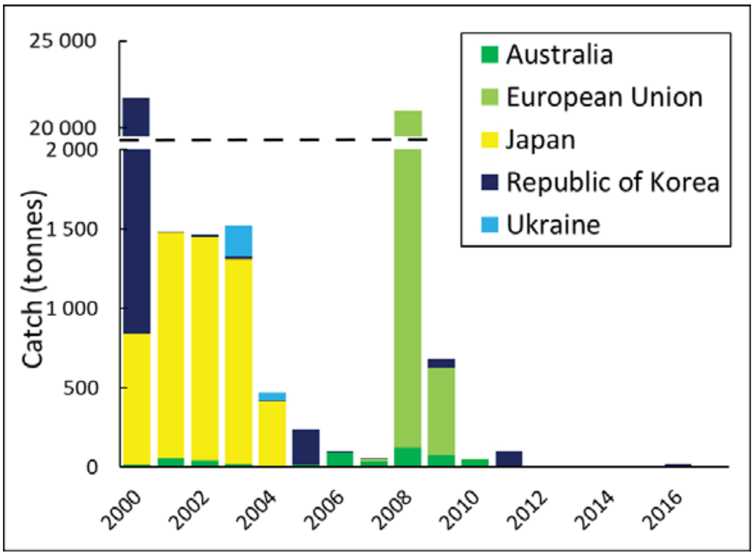
The South Pacific high seas fisheries continue to be dominated by New Zealand, which currently catches a total of around 1 000 tonnes per year – a decline when compared to the higher catches of 2 000–3 000 tonnes per year at the beginning of the century (Figure 12.10). Australia has been the only other nation to fish regularly in

FIGURE 12.10

Catches of fish of the SPRFMO area using demersal fishing gears by states and economic entities using bottom fishing gears: (a) main species reported as coming from the high seas, and (b) mixed species recorded as coming from the high seas and EEZs (note axis rescaling)



(a)



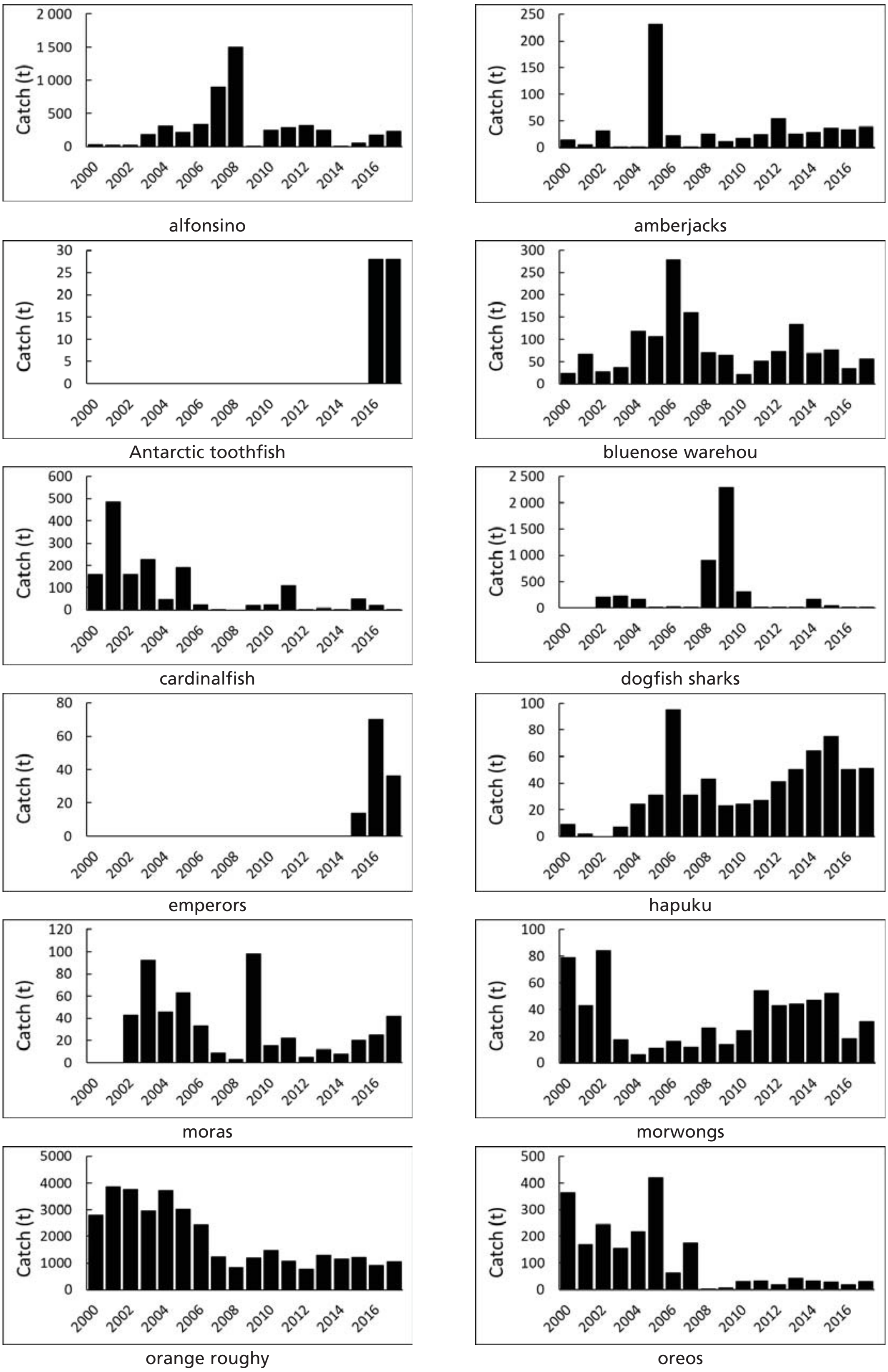
(b)

Source: SPRFMO, 2019.

the high seas in the twenty-first century, though catches vary from nothing to a few hundred tonnes each year. Belize, Chile, China, the European Union, the Republic of Korea and Ukraine have all fished for brief periods, usually targeting orange roughy, but these fisheries all only lasted a few years (SPRFMO, 2019).

Catches continue to be focused on orange roughy, mainly by New Zealand, with an overall decline from around 3 500 tonnes in 2000–2004 to stable values of a little over 1 000 tonnes (2006 to the present). Catches of common mora (ribald), cardinal fish and oreos follow a very similar temporal pattern to orange roughy and probably represent

FIGURE 12.11
Total catches (tonnes) of various fish species in the high seas of the SPRFMO area using bottom fishing gears



Source: SPRFMO, 2019.

a “targeted” bycatch of that fishery, with yields of 200–400 tonnes initially, declining to tens of tonnes more recently.

Catches of alfonsino (and to a lesser extent pelagic boarfish) by the New Zealand and Australian fleets, which are exploited separately to orange roughy using gear that is typically off though close to the sea floor, had their peak catches, of over 1 000 tonnes, in 2008 after the orange roughy had declined. However, catches have currently decreased to 169 tonnes in 2016.

The other significant high sea bottom fisheries were longline fisheries for various species including hapuka, bluenose warehou, yellow tail kingfish, and morwongs, emperors and snappers. Catches of hapuku, morwongs and emperors have increased over the last five years or so. Dogfish was mainly fished by Ukrainian fleets in 2002–2004, with annual catches of 163–218 tonnes, and just a few tonnes in recent years. Hapuku was fished by New Zealand vessels using longlines, with annual catches increasing over recent years though catches always remained below 100 tonnes (Figure 12.11). New Zealand has developed a small toothfish fishery with catches of 28 tonnes in both 2016 and 2017.

The 2016 catch from the high seas comprised 915 tonnes of orange roughy, 169 tonnes of alfonsino, and 426 tonnes of other species, mainly by New Zealand, giving a combined total of 1 510 tonnes (Table 12.1).

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13. Indian Ocean

FAO Major Fishing Area 51 and most of Area 57

SUMMARY

The high seas of the Indian Ocean are for the most part very deep and far exceed fishable depths. There are, however, several intersecting ridges containing rugged terrain and emerging seamounts with peaks at fishable depths, albeit at the limit of deep-sea trawling at around 700–1 800 m. These have supported a highly specialized bottom fishery, primarily for orange roughy and alfonsino, which demands great skill to place nets on fish aggregations accurately at such depths. These deep bottom fisheries started around 1998 and proceeded very rapidly through a boom-and-bust scenario prior to stabilizing at a low level with a handful of vessels from 2004. There are other deepwater fisheries using trawl nets and longlines south of Madagascar on Walter's Shoal catching a variety of species including sharks, and some in the extreme south targeting toothfish. The most extraordinary high seas fishery in the Indian Ocean is the very shallow fishery on Saya de Malha Bank on the Mascarene Plateau, northeast of Madagascar, at depths as shallow as 35 m fishing for sky emperor and other species. Deep midwater trawls are also used extensively, fishing just metres above the seabed, and these catches are not distinguishable from those where trawls are designed to touch bottom. Tows are usually fishing and in contact with the seabed for only 5–30 minutes.

Catches in the high seas of the Indian Ocean have been reported incompletely, particularly prior to 2010 and around Saya de Malha, especially for the minor target and bycatch species. Catches of alfonsino and deepwater sharks have increased between 2014 and 2016, whereas orange roughy catches remained similar. Total recorded catches in 2016 amounted to 7 734 tonnes, but these are likely to be grossly underestimated, especially when considering the fisheries on Saya de Malha Bank (Table 13.1).

Catches of deepwater species in the high seas are monitored and managed by the Southern Indian Ocean Fisheries Agreement (SIOFA) that entered into force in 2012 after some 13 years of preparatory discussions. There are now several control measures in place for bottom fisheries and the protection of benthos from significant impacts; the amount of information required for stock assessments and more directed management

TABLE 13.1
High seas bottom fisheries catch (tonnes) in the Indian Ocean for 2016

Gear	Grounds	Main flag states	Species	Catch
Handline and dropline	Saya de Malha	various	various	unknown
Midwater and bottom trawl	Seamounts	Australia, Cook Islands, Japan, Republic of Korea	alfonsino	4 900
		Australia, Cook Islands	orange roughy	1 034
Longline (and gillnet[1])	various	various	deepwater sharks (Squalidae)	1 800
		various	Hapuku, wreckfish and others	unknown
		France, Republic of Korea, Japan	Patagonian toothfish, blue antimora	unknown

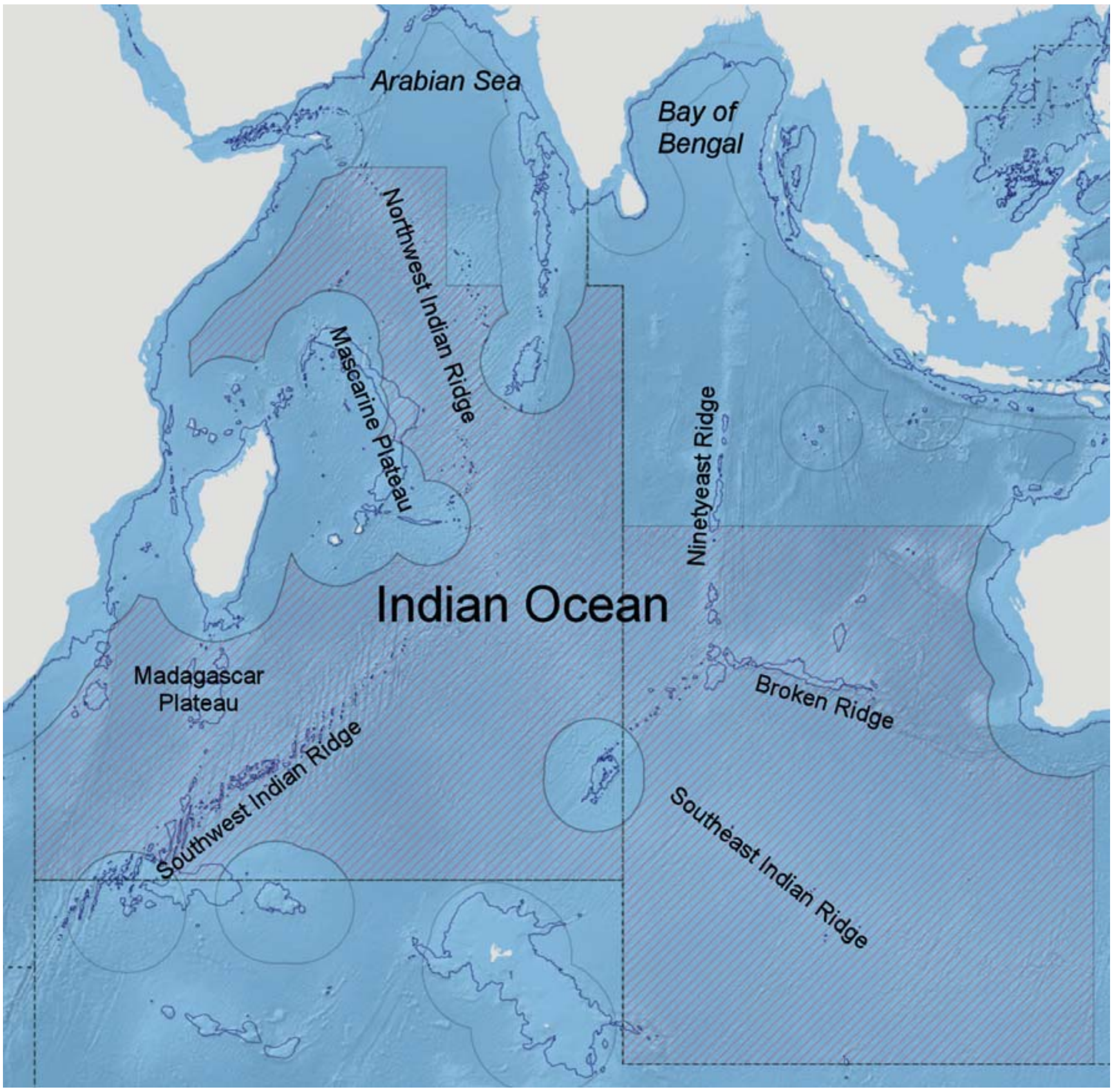
[1] Recommendation that gillnets should not be used under CMM 2016/05.
Source: Estimate based on reports available on SIOFA website (e.g. SIOFA, 2018b).

is also being increased. The region is also characterized by a management situation virtually unique in global fisheries, whereby an industry organization known as the Southern Indian Ocean Deepsea Fishers Association (SIODFA) has taken an active role in managing their members vessels and identifying sensitive areas that should be closed to demersal fishing by their members' vessels. Several states have incorporated these closed areas into their deep-sea management plans for their own flagged vessels, and in 2018 SIOFA adopted five of these for regional closures to bottom fishing.

GEOGRAPHICAL DESCRIPTION

The Indian Ocean is bounded by the land masses of Africa, Asia, and Australia and by the Southern Ocean to the south (Figure 13.1); its marginal seas are the Red Sea, Gulf of Aden, Gulf and Timor Sea, that are all under the jurisdictions of coastal states. The South Asian subcontinent divides the northern parts of the Indian Ocean into the Arabian Sea and the Bay of Bengal.

FIGURE 13.1
Map of the Indian Ocean showing SIOFA area (shaded)



200 nautical mile arcs, 2 000 m isobath (GEBCO), FAO fishing areas.

Source: FAO VME Database, Mercator projection.

There are only a few isolated islands in the Indian Ocean. Two seamounts on the Southeast Indian Ridge rise above the surface as *Île Amsterdam* and *Île St. Paul*, both being parts of the French *Territoire des Terres australes et antarctiques françaises*. In the east are Australia's Cocos (Keeling) Islands and Christmas Island. Each of those four is surrounded by an EEZ. The Sub-Antarctic islands of the Prince Edward and Crozet groups lie outside the region, as it is delimited here, but close enough that the EEZs around them overlap it.

Most of the region is deep ocean, surrounded by narrow continental shelves. Even where the shelves are wider, particularly off Myanmar and on Australia's Northwest Shelf, they do not project into the high seas. The Indian Ocean's abyssal plains are divided by several ridges, of which the most prominent are the Southwest Indian, Northwest Indian and Southeast Indian ridges. These are mid-ocean tectonic spreading centres which merge at the "Rodrigues Triple Junction" where the African, Indo-Australian and Antarctic plates meet. The Southwest Indian Ridge and the Northwest Indian Ridge near the Triple Junction are typical rugged features, whereas the Southeast Indian Ridge is broader and lower. The Northwest Indian Ridge merges into the Chagos-Laccadive Plateau and the Lakshadweep Islands, Maldives and Chagos Archipelago. The EEZs around these islands separate the northwestern and northeastern high seas areas of the region, and cover most of the seabed that lies at potentially fishable depths.

The Madagascar Ridge, the Mascarene Plateau and adjacent bathymetric features bear multiple islands, including the large landmass of Madagascar, and have extensive areas of national EEZs. The Mascarene Plateau includes the extensive Saya de Malha Bank – an important high seas feature with a service area of 42 000 km^2; mainly formed from a large submerged atoll, the Bank's depth at its rim is 7–30 m but includes a broad lagoon shallower than 200 m. This is one of the shallowest high seas areas in the world.

The only other areas of fishable depth within the high seas are on the summits and flanks of seamounts, most of which occur along ocean ridges. Their combined area < 1 000 m is only some 50 000 km^2, though there is considerably more bottom at depths between 1 000–2 000 m (Table 13.2). Most are on one or another of the Southwest Indian, Madagascar, Southeast Indian, Ninety East or Broken ridges – the first of which has proven to be the most productive. Areas relating to the various depth layers on the main bottom fishing grounds are summarized in Table 13.3.

TABLE 13.2
Area statistics for the Indian Ocean

Description	Area (km^2)
Total sea area	55 315 000
Area of high seas	35 588 000
Area of high seas shallower than 200 m	38 000
Area of high seas shallower than 400 m	59 000
Area of high seas shallower than 1 000 m	95 000
Area of high seas shallower than 2 000 m	515 000

ECOSYSTEMS AND RESOURCE SPECIES

South of the Equator, the oceanography of the Indian Ocean resembles those of the South Pacific and South Atlantic, with an anti-clockwise gyre that receives some cold water from the Antarctic Circumpolar Current, though much of this then passes south along western Australia as the Leeuwin Current. In the southwest, the Indian Ocean's western-boundary current is the Agulhas Current, which follows the coast of southern Africa, some of its water rounding the Cape to enter the Atlantic, while the rest turns eastward as the "Agulhas Retroflection" to join the major circumglobal flow. The

TABLE 13.3
Depth profiles (percent) and total area (km²) of selected areas within the main fishing areas

	0–200	201–700	701–1 000	1 001–1 500	1 501–2 000	> 2 000	Total	Total area (km²)
Saya de Malha Bank	42.1	29.6	3.0	8.1	9.7	7.5	100.0	47 856
Walter's Shoal	0.2	1.5	13.3	28.7	34.0	22.3	100.0	77 973
Southwest Indian Ridge	0.0	0.3	0.3	2.5	13.4	83.5	100.0	89 467
Ninety East Ridge & Amsterdam Fracture zone	0.0	0.1	0.5	1.4	2.1	95.9	100.0	91 163
Broken Ridge	0.0	0.3	13.3	61.2	15.2	9.9	100.0	6 405
Southwest Indian Ridge (southern)	0.1	0.9	1.2	5.5	15.5	76.7	100.0	43 151
Del Cano Rise	0.0	0.0	0.6	22.9	52.5	24.0	100.0	18 003
SIOFA Area	0.1	0.1	0.1	0.4	1	98.3	100.0	35 588 000

Source: Anon, 2017a.

Indian Ocean is unique north of the equator, truncated at the Tropic of Cancer by the Asian landmass, divided into two basins by South Asia, and subject to the seasonally alternating winds of the Southwest and Northeast monsoons. Gyres form in the Arabian Sea and the Bay of Bengal, and these also show seasonal changes in direction (Figure 13.2).

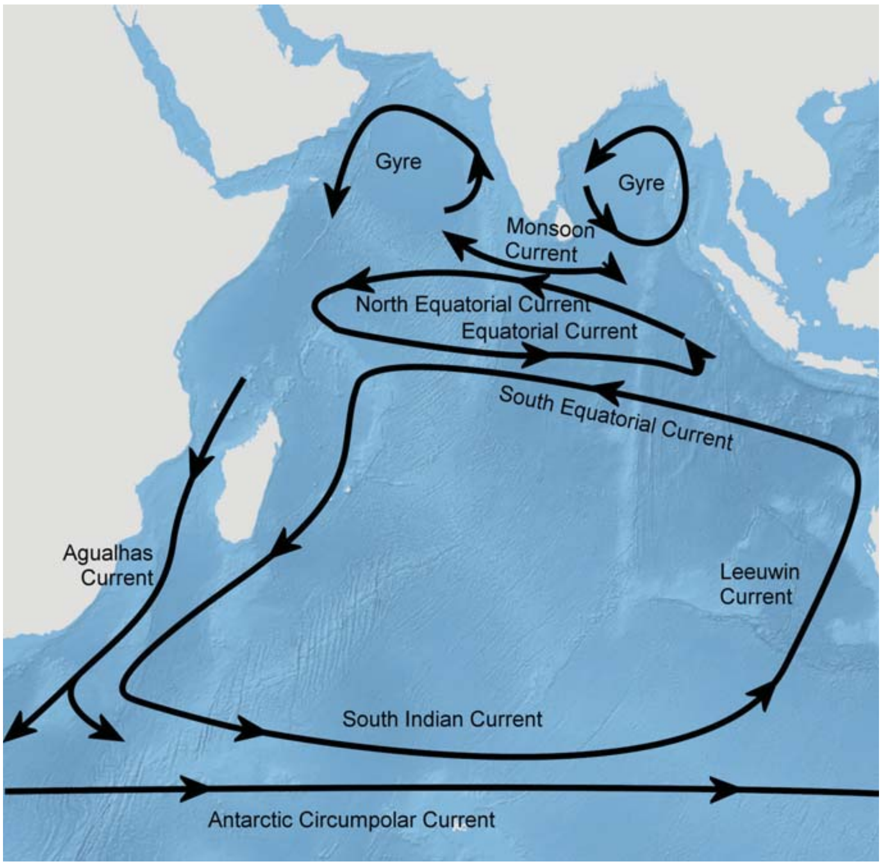
The Indian Ocean has no highly productive, current-driven upwelling ecosystems, as in the other large oceans. There are areas of high productivity within the basins, notably in the Arabian Sea, but in the high seas this occurs only around Saya de Malha Bank, and on some of the seamounts in temperate southern latitudes, primarily south of 35° S. The seamounts support ecosystems broadly similar to those seen elsewhere along the ridges and plateaus (Rogers, 2012). The Indian Ocean supports a wide range of deepwater fisheries and species, though only a few are really targeted (Figure 13.3).

The Saya de Malha Bank is a shallow extension of the Mascarine Plateau into the high seas with depths of mostly less than 200 m with extensive flat trawlable ground. Some 70 percent of the area is less than 700 m deep, and therefore suitable for exploitation by smaller vessels of less than 500 gross tonnes, such as those used by Thailand. The principal exploited resource species on Saya de Malha Bank exploited by Mauritian fishers is the is the sky emperor, known to the Francophone fishermen as *dame berri*. There is also a separate directed bottom fisheries for a wide variety of other species including scads, lizardfishes, crimson jobfish, while longtail red snapper has been taken there by distant-water fishermen. In the past, there have been attempts to develop trawl fisheries within the central lagoon but they did not lead to any commercial activity.

Walter's Shoal is a high seas extension of the Madagascar Plateau at a moderate depth, with extensive areas in the 700–1 500 m range. It has the most extensive grounds suitable for bottom trawling in the high seas of the Indian Ocean, though the depths are such that larger vessels are needed when compared to trawling on the Saya de Malha Bank. Species caught here are similar to the ridges and seamounts and include alfonsino, orange roughy, pelagic amorhead, warehou and cardinal fish.

The main fished ridges of the southern Indian Ocean are the Southwest Indian Ridge, as well as around and close to the junction of the Amsterdam Fracture Zone and Ninety East Ridge, and Broken Ridge. These are deep, rugged features with little ground above 1 500 m depth; they offer only a few suitable locations for specialized and highly targeted bottom trawling with nets on the bottom for only 5–30 minutes.

FIGURE 13.2
Principal currents in the Indian Ocean



Source: FAO VME Database, currents added.

Broken Ridge is shallow and has more extensive areas at 700–1 500 m depth, but the whole Ridge is very rugged with no real opportunity to use bottom trawls. There is an increasing tendency to favour the use of deep midwater trawls on these ridges and seamounts to target all species except orange roughy. The seamount fisheries have taken a wide variety of species, most notably orange roughy and alfonsino but also: rubyfish, cape bonnetmouth, various centrolophids (mostly rudderfish, bluenose warehou and ocean blue-eye trevalla), oreo dories, cardinalfish, wreckfish and Portuguese dogfish (*Centroscymnus* spp. – though uncertainty remains over the species taken).

Patagonian toothfish are found in the far south on the southwestern extremity of the Southwest Indian Ridge and around Del Cano Rise, situated between and to the north of Prince Edward and Crozet island groups. Patagonian toothfish are however mainly distributed in the Southern Ocean. Grenadiers and other species are also found here and caught in the bottom-set longline fishery.

MANAGEMENT OF HIGH SEAS BOTTOM FISHERIES

Southern Indian Ocean Fisheries Agreement (SIOFA)

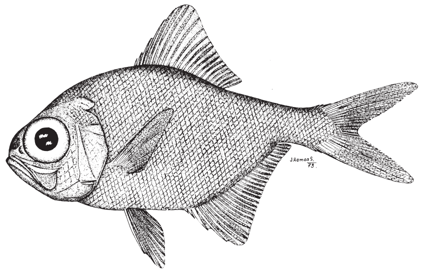
Origins and structure

In 1999, the FAO Council abolished the former Indian Ocean Fishery Commission, following the establishment of the Indian Ocean Tuna Commission, which had taken over its predecessor's primary responsibilities (FAO, 1999). However, that change eradicated the former commission's subsidiary bodies, including its Committee for the Development and Management of Fisheries in the Southwest Indian Ocean. At the time, distant-water high seas bottom fishing had only recently begun in the region and

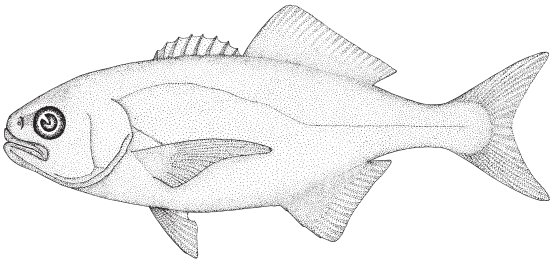
FIGURE 13.3
Principal demersal resource species of the high seas of the Indian Ocean

dogfish *Centroscymnus coelolepis*[1]

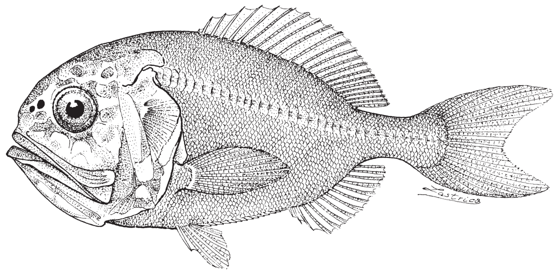
alfonsino *Beryx decadactylus*[1]



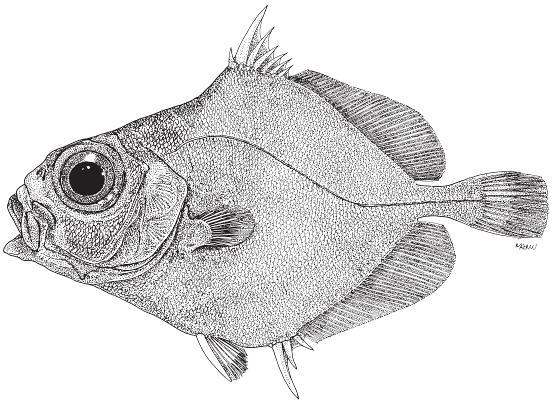
bluenose warehou *Hyperoglyphe antarctica*[1]



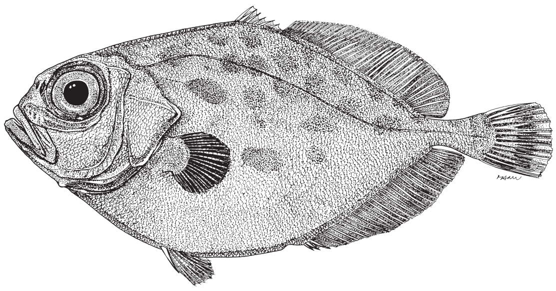
orange roughy *Hoplostethus atlanticus*[2]



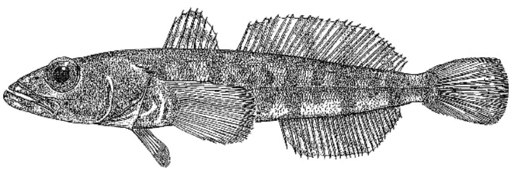
Spiky oreo *Neocyttus rhomboidalis*[1]



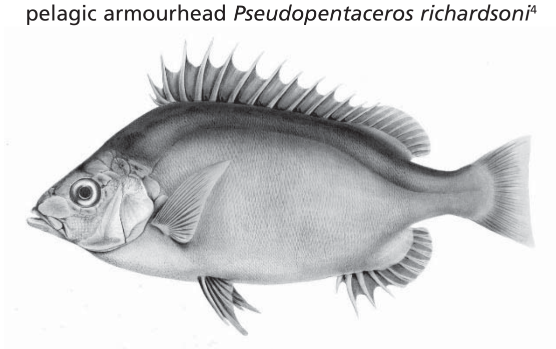
Smooth oreo *Pseudocyttus maculatus*[1]



Patagonian toothfish *Dissostichus eleginoides*[3]



pelagic armourhead *Pseudopentaceros richardsoni*[4]



Source:
[1] Food and Agriculture Organization of the United Nations, Original Scientific Illustrations Archive.
[2] www.fao.org/fishery/species/2249/en
[3] Fischer and Hureau (1985).
[4] Smith (1849).

the subregional focus of the former subsidiary bodies had been on fishing conducted by the fleets of coastal nations in their own EEZs (Marashi, 1996).

In 2000, FAO convened two technical meetings to consider the establishment of a new regional body for the southwest Indian Ocean. This led to the establishment of the South West Indian Ocean Fisheries Commission (SWIOFC) for the coordination of coastal states and to advise on fisheries management within EEZs, and the *Southern Indian Ocean Fisheries Agreement* (SIOFA), which would adopt binding decisions on the management of high seas fisheries.

Concerns over the potentially rapid depletion of orange roughy and other deepwater species in the Indian Ocean were expressed in 2004 at the Fourth Intergovernmental meeting (FAO, 2005); a resolution on data collection was adopted, and companies and countries were asked to develop protocols to pool data. Countries fishing in the area were also asked to take management actions to control catch and effort. The data collection scheme was included in the adopted SIOFA Agreement in 2006 (SIOFA, 2006).

SIOFA entered into force in 2012, and the decision-making body known as the "Meeting of the Parties" (MoP) met from 2013, with the scientific committee meeting for the first time in March 2016. To date, there are nine contracting parties: Australia, Cook Islands, European Union, France (on behalf of its Indian Ocean territories), Republic of Korea, Japan, Mauritius, Seychelles and Thailand.

Having grown from a specifically southwestern focus to incorporate the distant-water fishery that emerged at the turn of the century, the SIOFA "Area of Application" includes most of the Indian Ocean except the Arabian Sea, the Bay of Bengal, the northeastern Indian Ocean, and waters under national jurisdictions (Figure 13.1). There are no significant bottom fisheries in the high sea portions of the Indian Ocean north of the area, and no RFMO/A has been established here. The southern boundaries border those of SEAFO, CCAMLR and SPRFMO. The SIOFA Agreement applies to resources of fish, molluscs, crustaceans and other sedentary species, except specified highly migratory species and sedentary species subject to coastal state jurisdiction.

The objectives of SIOFA are the long-term conservation and sustainable use of fishery resources, in addition to the promotion of the fisheries' sustainable development, taking into account the needs of the developing states that border the Area of Application. The agreement binds the parties to apply both the best scientific evidence available and the precautionary approach, while maintaining resources at levels capable of producing the maximum sustainable yield, minimizing the harmful impact of fishing activities, protecting biodiversity and recognizing the special requirements of developing states.

Fisheries and resource management

The interim (and originally voluntary) standards for data reporting, developed in 2004 do not appear to have been implemented by any country, and no data on Indian Ocean high seas bottom fisheries are reported internationally (Bensch *et al*., 2009), except for the catch reporting to FAO which is aggregated by Major Fishing Area. However, there was information to suggest that stocks of the longer-lived orange roughy and oreo were declining and fishers were turning to the shorter-lived, more productive alfonsino and pelagic armourhead. Effort had decreased from a peak of over 40 vessels in 1999–2000 to 6–10 vessels around 2005, which often made only a few unprofitable trips (FAO, 2005).

SIOFA adopted its first Conservation and Management Measures in 2016 and extended these in 2017. This laid the foundations of fisheries management, covering fundamental requirements such as data collection, reporting and confidentiality, and port inspection schemes: including a register of designated landing ports, vessel lists and monitoring with logbooks and VMS, *etc*. (SIOFA, 2018a). The use of pelagic drift nets over 2.5 km in length was prohibited and it was recommended that deepwater gillnets not be used.

The interim management measures for bottom measure were adopted in 2016 and revised in 2017 and 2018 (CMM 2018/01; SIOFA, 2018a). This measure promotes the sustainable management of deep-sea fisheries resources for target and non-target species, and the protection of the marine environment including the prevention of significant adverse impacts on vulnerable marine ecosystems (VMEs). This measure identifies the steps to be undertaken by fishing nations and the scientific committee, mostly directed towards avoiding significant adverse impacts on VMEs through impact assessments, encounter protocols, and the closure of areas containing VMEs. Until SIOFA has adopted its own unified measures the responsibility lies with the fishing nations. The scientific committee is required to assess the status of the principal targeted deep-sea fish stocks by 2019 – as well as bycatch species, if possible. These assessments will be aided by the use of observers or electronic logbook reporting. There are no catch or strict effort limits, though fishing states have been asked not to expand their effort or fishing area.

The Meeting of Parties, in 2017, recommended that contracting parties note the advice given by the scientific committee concerning the Benthic Protection Areas (BPAs) (CMM 2017/01). The following year, SIOFA designated five protected areas and closed them to fishing with bottom contact gears other than lines and traps (CMM 2018/01).

Scientific support to management

The fisheries management decisions made at the Meeting of the Parties are supported by advice from the scientific committee which first met in 2016. The scientific committee has developed various time-sensitive plans to undertake its main duties, in line with six themes: (a) scientific data standards, (b) vulnerable marine ecosystems, (c) current and historical status of fishing activities, (d) stock assessments, (e) impacts of fishing on associated and dependent species, and (f) any other advice that the MoP requests.

They have prioritized research and assessment on orange roughy, alfonsino, Patagonian toothfish, and deepwater sharks. Progress has been made on stock identification for orange roughy along with an initial assessment of the Walter's Shoal Region, and on the collection of fishing methods, effort and catch statistics from contracting parties. The scientific committee has also made progress on standards relating to bottom fisheries impacts assessments (BFIA) and on the development of a regional bottom fishing footprint from the national footprints submitted. This will allow the committee to provide advice on new and exploratory fisheries, and to monitor those fisheries currently occurring within the existing fishing footprint more effectively.

SUPPORT FROM INDUSTRY

Southern Indian Ocean Deepsea Fishers Association (SIODFA)

Industry representatives were present in the negotiations to form SIOFA and, in response to the call for data collection, formed the Southern Indian Ocean Deepsea Fishers Association (SIODFA)[1] from four fishing companies active in 2006, with the objectives of promoting responsible management of the resources, ensure sustainable harvests, and conserving biodiversity. This was an attempt for commercial companies with a vested interest to maintain long-term sustainable fisheries in the high seas of the Indian Ocean. SIODFA identified and closed 12 Benthic Protected Areas (BPAs) covering a total of 223 942 km^2 in the Indian Ocean to bottom fishing by their members. Another area in the southeast Atlantic Ocean south of South Africa was also closed to bottom fishing by their members.

[1] http://siodfa.org/

Other initiatives include the use of VMS and the collection of biological data on catches, similar to those gathered in other regions by observers. Acoustic surveys of resource biomass have also been undertaken (FAO, 2006; SIOFA, 2018b).

DESCRIPTION OF HIGH SEAS BOTTOM FISHERIES

The bottom fisheries of the southern Indian Ocean, including those catching demersal species with deep midwater trawls, have been subject to great change in terms of fishing nations, areas fished and catch composition. Modern seamount trawling reached the southern Indian Ocean in 1998 and the success of the first trawlers fishing for orange roughy on the Southwest Indian Ridge led to the explosive development of an international fishery during 2000–2001, followed by its equally rapid collapse. In the absence of any RFMO/A with competence over the fishery, the subsequent stability thereafter seems to have been achieved with much reduced effort and fewer vessels.

There are currently nine areas that have been subject to various intensities of bottom fishing, and some of these have been fished on and off since the early exploratory fisheries in the 1960s (Figure 13.4). Deep midwater trawling is the most common gear used, mainly due to the general lack of suitable bottom trawl areas throughout the Indian Ocean high seas. Bottom-set longlining is common in most areas, and bottom-set gillnetting has been used in the recent past, though this finished around 2013 following requests by SIOFA to halt this practice until its impacts are better understood. There are a wide range of target species caught in generally mixed fisheries including jobfish, snappers, porgies, groupers, emperors and deepwater sharks. More directed fisheries, typically with little bycatch, occur for orange roughy using aimed bottom trawls, for alfonsino using midwater trawls, and for Patagonian toothfish using bottom-set longlines.

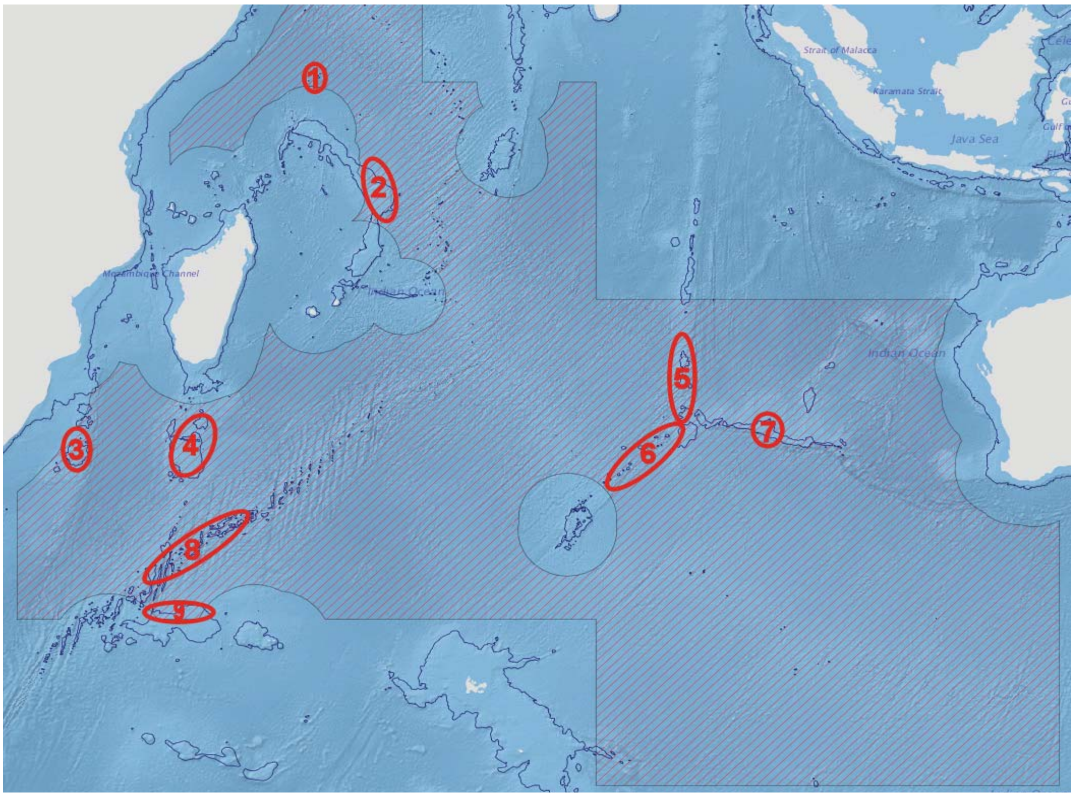
Much of the information for the Indian Ocean is fragmentary, especially before SIOFA assumed a coordinating role around 2010. This is especially so for the period around 2000, when there was a very rapid and short-lived expansion of fishing effort. Ranges of years given in the text below are hopefully correct, but it should not be assumed that fishing did not occur before the given period, as in many cases this may simply reflect a lack of reporting.

Saya de Malha Bank

Commercial high seas bottom fishing in the Indian Ocean likely first commenced at very shallow depths on Saya de Malha Bank. In 1967, and following a number of exploratory efforts, Mauritian fishermen began a banks fishery with mother ships, each fitted for freezing the catch and carrying multiple “dories”, from which the fishermen worked handlines. They worked across the banks of the Mascarene Plateau, but latterly they have focused their efforts on Saya de Malha and Nazareth Banks which extend into the high seas. The catch is around 90 percent sky emperor taken in areas of mixed coral heads and seagrass at depths of 18–60 m, though usually at less than 35 m. The remainder of the catch comprises assorted groupers, snappers and emperors, plus a few tuna (Lebeau and Cueff, 1975; Munbodh, 2014).

There have been other attempts to develop bottom fisheries on and around Saya de Malha Bank, though ultimately unsuccessful. As in so many other regions of the World Ocean, vessels from the former USSR explored grounds in the Indian Ocean from the early 1960s onwards, with Japanese vessels joining them in the 1970s. Initial trips from 1961 went to the African continental shelf, but there was also some exploration of the Bank as early as then (Vortsepneva, 2008). Japanese trawlers explored the shallow waters of the Mascarene Plateau, including the high seas portion of the Bank, during 1977–1978. They took 1 076 tonnes of assorted species, mostly mesopelagic bigeye and Japanese scad and lizardfish (Clark *et al.*, 2007; Anon., 2017b). The area was then left to the Mauritian fishers for nearly two decades.

FIGURE 13.4
Main bottom fishing grounds in the high seas of the Indian Ocean



Key

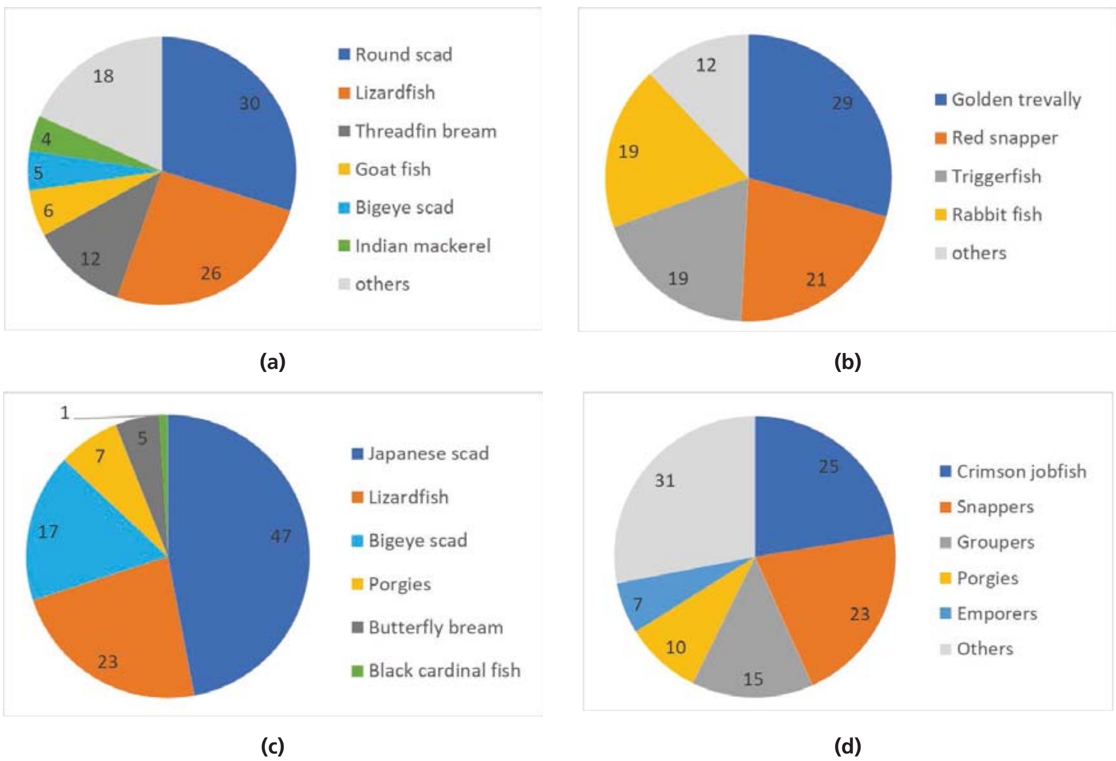
No	Area
1	Madagascar Plateau - North
2	Saya de Malha Bank (Mascarine Plateau)
3	West Walter's (Mozambique Plateau)
4	Walter's Shoal
5	Ninety East Ridge
6	Amsterdam Fracture zone
7	Broken Ridge
8	Southwest Indian Ridge
9	Del Cano Rise

Source: FAO VME Database, locations added.

From 2000 onwards, the Saya de Malha Bank has also been fished by vessels from Thailand, Japan, China and France using bottom trawls, midwater trawls, traps and longlines. Mauritius presumably continued to fish, but the extent of the fishing is not currently known. Thailand is the principal nation currently fishing on the high seas portion, with some 62 bottom trawl vessels active in 2015–2017; most are relatively small for high seas fishing, at 100–500 gross tonnage, with a few up to 1 200 GRT. Their target species are scad and lizardfish, which made up over 55 percent of the catch totalling nearly 36 000 tonnes for 2015–2017, with other species forming the balance of the catch. A single vessel from Thailand also operated a trap fishery in 2016–2017 taking mainly golden trevally, but with a high proportion of red snapper, triggerfish and rabbitfish (Anon, 2018). Japan operated an exploratory bottom trawl fishery in 1978–1979, catching similar species, and recorded bycatches of barracuda, kingfish and sea basses, whereas France fished with bottom-set longlines in 2009–2017, catching mainly crimson jobfish and snappers (Figure 13.5). China reported bottom longline fishing on Saya de Malha Bank with limited effort and unspecified catches in 2004–2006. However, in 2005 four Chinese longliners targeted longtail red snapper in an exploratory survey of the Bank, the fleet increasing to seven vessels the following year. They took 756 tonnes of the target species and 214 tonnes of bycatch during the two years (Bensch *et al*., 2009; Heileman *et al*., 2015).

While the catches from Saya de Malha are not large, at less than one tenth of the peak catches of the seamount fisheries further south, they represent a very important fishery for nations utilizing smaller trawlers and support the livelihoods of fishers and processors from Mauritius and Thailand, as well as those nations with larger vessels that are also capable of fishing in deep waters.

FIGURE 13.5
Catch composition from selected fleets using: (a) bottom trawls in 2015–2017 and (b) portable traps in 2016–2017, (c) bottom trawl in 1977–1978, and (d) longlines in 2009–2017, fishing on Saya de Malha



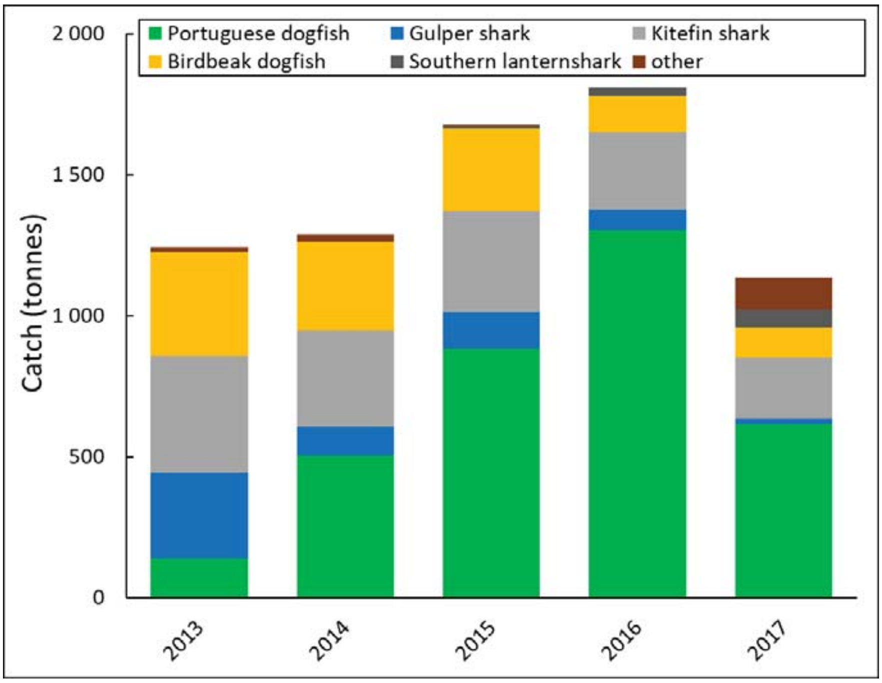
Source: SIOFA, 2018b.

Walter's Shoal and West Walter's

Walter's Shoal lies south of Madagascar on the Madagascar Plateau and has been fished by Australia, Japan and Cook Islands – mainly with midwater trawls, though bottom trawls were commonly used by the Cook Islands between 1996–2016, probably for orange roughy, and Japan had a small exploratory fishery there in 1977–1978 and 2012. Details of fishing operations on Walter's Shoal have not been distinguished from those of the ridges and seamounts given below, though catches and fishing methods appear to be similar. The proportion of bottom trawling is higher here than elsewhere in the high seas of the Indian Ocean, owing to a greater availability of suitable trawling grounds at 700–1 500 m depth.

There is also a Spanish targeted deepwater shark fishery currently focused on Walter's Shoal; however, it has also fished on West Walter's on the Mozambique Plateau in the recent past, using longlines and catching mainly Portuguese dogfish with a bycatch of other elasmobranch species such as birdbeak dogfish, kitefin shark and gulper shark (SIOFA, 2019). Reported catches of deepwater shark by SIOFA contracting parties from all areas for 2013–2016 have steadily increased from 1 200 to 1 800 tonnes over the period (Figure 13.6): this caused the SIOFA scientific committee to prioritize the development of identification and data collection protocols for elasmobranchs (SIOFA, 2018b).

FIGURE 13.6
Provisional annual catches for deepwater sharks from the high seas of the Indian Ocean by SIOFA contracting parties



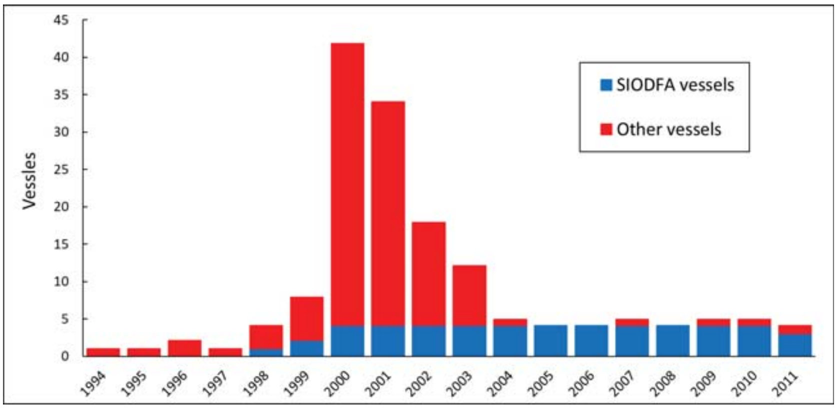
Source: SIOFA, 2019.

Seamounts and ridges

In the late 1960s, research trawlers on their way to and from survey work in the Southern Ocean extended the explorations of the Black Sea fleet of the former USSR to the Southwest Indian Ridge. Expeditions specifically directed towards the southern Indian Ocean followed from 1978 (Romanov, 2003). Commercial fishing commenced in 1980, while scouting operations spread to the Madagascar, Southeast Indian, Ninety East and Broken Ridges over the next year or two – though the fishing on the eastern ridges ended in 1984 after taking little more than 1 000 tonnes in all, most of it in the first year. Indeed, the former USSR fishery in the southwest also fell to a very low level that same year, briefly recovering in 1987 before dying away during the economic disruptions of the break-up of the former USSR. Reported catches under 18 000 tonnes for the decade of fishing, two-thirds of it taken in the first two years. In 1980 and again in 1987 the commercial catches in the southwest were primarily rubyfish, cape bonnetmouth, rudderfish and bluenose warehou, though alfonsino dominated from 1981 to 1983. The catches also included cardinalfish and wreckfish, while the eastern ridges yielded a similar mix of species. From 1992 until 2002, the Ukrainian fleet returned to the Southwest Indian Ridge, targeting primarily alfonsino and taking 12 900 tonnes along with 8 600 tonnes of bycatch species, but that fishery then died away once more (Clark *et al.*, 2007; SIODFA website).[2]

From 1995, the Australian and New Zealand orange roughy fleets, which were already active in the Tasman Sea, began to explore the ridges of the southeastern Indian Ocean. The first initiative was a bathymetric survey of promising seabed features, which lead to commercial fishing from 1998 using the aimed trawling techniques developed around New Zealand over the previous several years. In the east most of their effort focused on seamounts on Ninety East Ridge at depths of 800–1 000 m, but those could only be fished by deep midwater trawling. Orange roughy were then found in some abundance on the Southwest Indian Ridge and to a lesser extent on the southern portion of the Madagascar Ridge. A mixed fishery emerged for roughy, cardinalfish, wreckfish, oreos and alfonsino: the Southwest Indian Ridge yielded higher roughy catches while those taken on the Madagascar Ridge tended to be more diverse. Vessels from other nations were attracted to the fishery, encouraged in part by the closure of the South Tasman Rise grounds in the high seas south of Tasmania. An international fleet of nearly 50 deep-sea trawlers, under many flags, fished the Southwest Indian Ridge in 2000 and 2001, in an unregulated "gold rush". The number of fishing vessels quickly diminished and has remained at five vessels or fewer annually since 2004, almost entirely composed of SIODFA members (Figure 13.7; SIODFA, 2018b). These figures do not include the vessels fishing in the comparatively shallow Saya de Malha Bank.

FIGURE 13.7
Fleet size of fishing vessels reporting landings in the Southern Indian Ocean deepwater high seas fishery, showing the proportion of SIODFA members

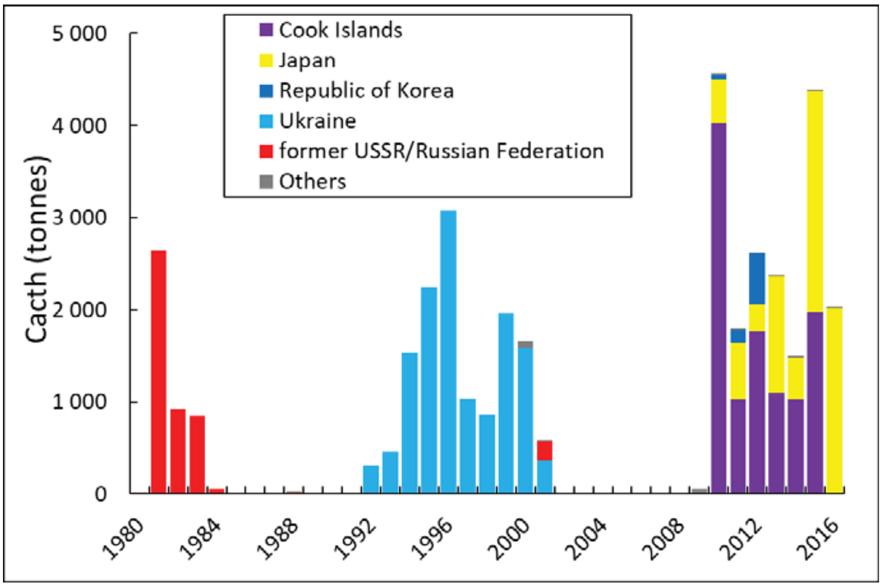


Source: SIODFA, 2018.

Reports of historical catches of alfonsino and orange roughy to FAO, which are almost entirely in the high seas – though alfonsino may include some EEZ catches – are lower than expected based on other sources, though the information does appear to be more accurate from 2010 when countries started to ratify the SIOFA agreement (Figure 13.8 and Figure 13.9; FAO, 2019). The almost total absence of alfonsino catches reported to FAO for 2002–2009 is most likely as a result of a lack of full reporting. Higher catches were reported by Clark *et al.* (2007) giving the total catch in 1999 as 14 500 tonnes, including 5 200 tonnes of orange roughy and 2 600 tonnes of alfonsino; the following year the total exceeded 39 000 tonnes, with more than 12 000 tonnes of roughy and 6 500 tonnes of alfonsino. Nonetheless, Clark *et al.* (2007) note that catches fell sharply after 2001.

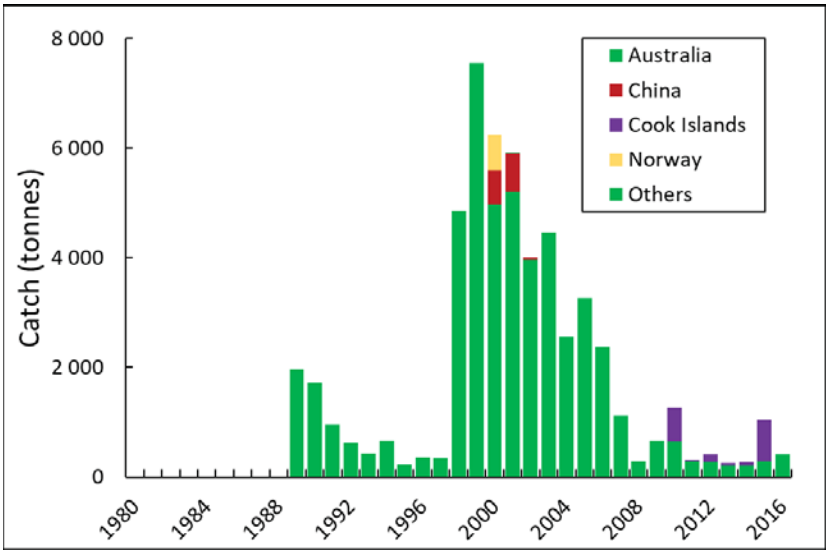
[2] http://www.apsoi.org/

FIGURE 13.8
Catch of alfonsino reported to FAO for the western and eastern Indian Ocean (high seas and EEZs combined)



Source: FAO, 2019.

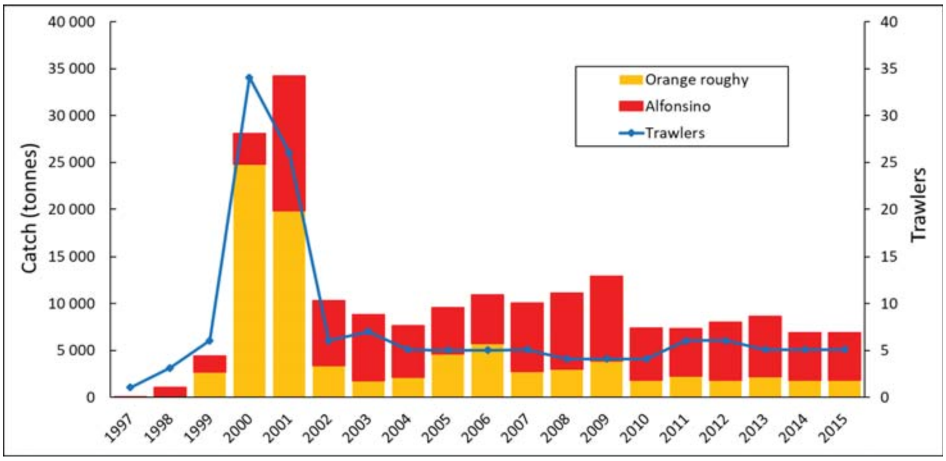
FIGURE 13.9
Catch of orange roughy reported to FAO for the western and eastern Indian Ocean (high seas and EEZs combined)



Source: FAO, 2019.

In 2016, Cook Islands presented an alternative catch history to the SIOFA Scientific Committee in the form of a graph of Indian Ocean orange roughy and alfonsino catches, plus vessel numbers, covering 1997–2015 (Figure 13.10) (SIOFA, 2016: Annex I). The committee was not able to verify the graph, which drew on data compiled from catch and landings records. The Cook Island estimates show catches peaking at around 30 000 tonnes in 2000–2001 and thereafter dropping to 10 000 tonnes or lower annually, where they have remained. The Cook Island

FIGURE 13.10
Indian Ocean fishery catch and number of trawlers for 1997–2015 in the SIOFA area: information provided to SIOFA Scientific Committee by the Cook Islands



Source: redrawn from SIOFA, 2016, Annex I.

estimates show higher peak catches and much less annual variability in both orange roughy and alfonsino catches, compared to those catches formally reported to FAO, though they are broadly similar after 2010. The number of vessels fishing – which does not correlate well with effort, as many vessels fish in other regions as well – is similar (Figure 13.7 and Figure 13.10).

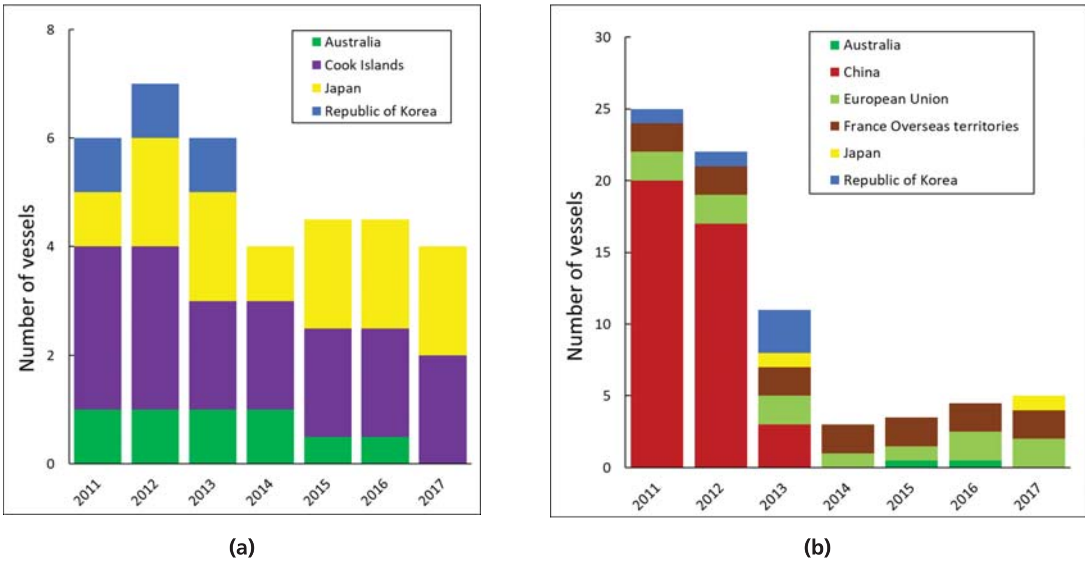
The SIOFA contracting parties (Australia, Japan, Republic of Korea, Thailand, and Cook Islands) and a non-contracting party (China) submitted more complete national statistics and bottom fisheries impact assessments to the SIOFA Scientific Committee in 2018 (SIOFA, 2018c). Currently, in 2011–2017, and excluding the fisheries on the Saya de Malha Bank, around 4–7 deepwater trawl vessels from Australia, Cook Islands, Japan and the Republic of Korea fished in the SIOFA area, though the republic of Korea have not fished since 2013.

In general, midwater trawls are favoured throughout this region owing to the difficulty in deploying aimed bottom trawls that are usually on the sea floor for less than 20 minutes. However, the preferred method for catching orange roughy is the aimed bottom trawl. For example, in 1999–2009 Australia used about 60 percent midwater trawls and 40 percent bottom trawl; the Cook Islands used about 70 percent midwater and 30 percent bottom trawls. Bottom longline vessels have shown a decreasing trend with 25 vessels fishing in 2011, dropping to 3–5 vessels for 2014–2017, a decline which is due to the cessation of longline fishing by China and the Republic of Korea in 2013 (Figure 13.11). Some of these longline vessels likely include those that have been fishing for Patagonian toothfish in the south of the region (SIOFA, 2018b, 2019).

Fishing effort was also reported to SIOFA: a comparison of Figure 13.11 and Figure 13.12 reveals that vessels expend different amounts of effort depending on whether the Indian Ocean is a major fishing ground or one combined with fishing in other regions (mainly the Southern Ocean for longline vessels). Some of the longline effort is likely for Patagonian toothfish in the south of the region, though significant longlining does occur on the main ridges (SIOFA, 2018b).

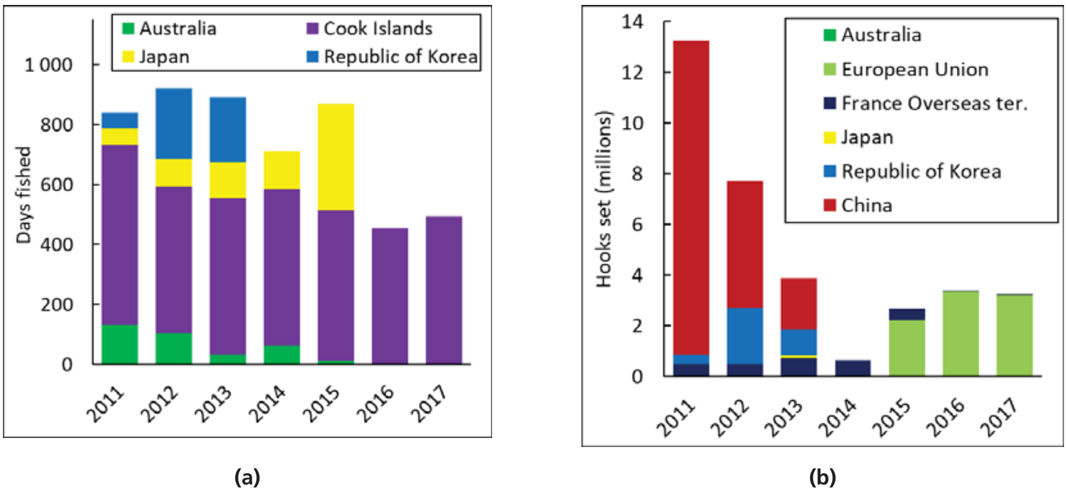
Total catches of orange roughy and alfonsino in the high seas of the Indian Ocean, combined for all countries that submitted information and mainly coming from the seamounts, ridges and Walter's Shoal, show orange roughy catches of 1 000–2 500 tonnes (Figure 13.13) and alfonsino catches of 3 000–7 000 tonnes for 2006–2016 (Figure 13.14) with the variation likely due to changes in the number of

FIGURE 13.11
Number of deep-sea (a) bottom trawl and (b) longline vessels fishing the high seas of the Indian Ocean



N.B. Vessels fishing Saya de Malha Bank have been excluded.
Source: SIOFA, 2018b.

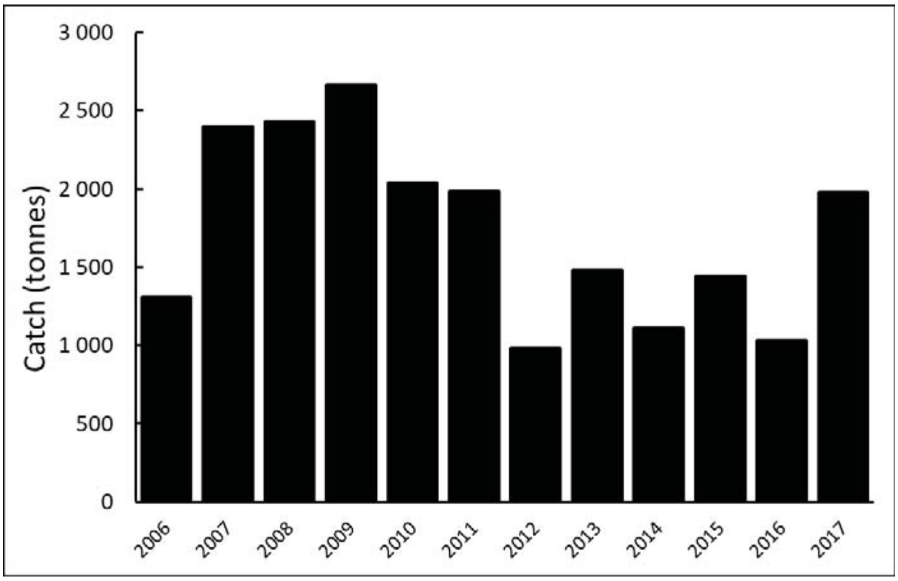
FIGURE 13.12
Deep-sea fishing effort: (a) bottom trawl and (b) longline vessels fishing the high seas of the Indian Ocean



N.B. Vessels fishing Saya de Malha Bank have been excluded.
Source: SIOFA, 2018b.

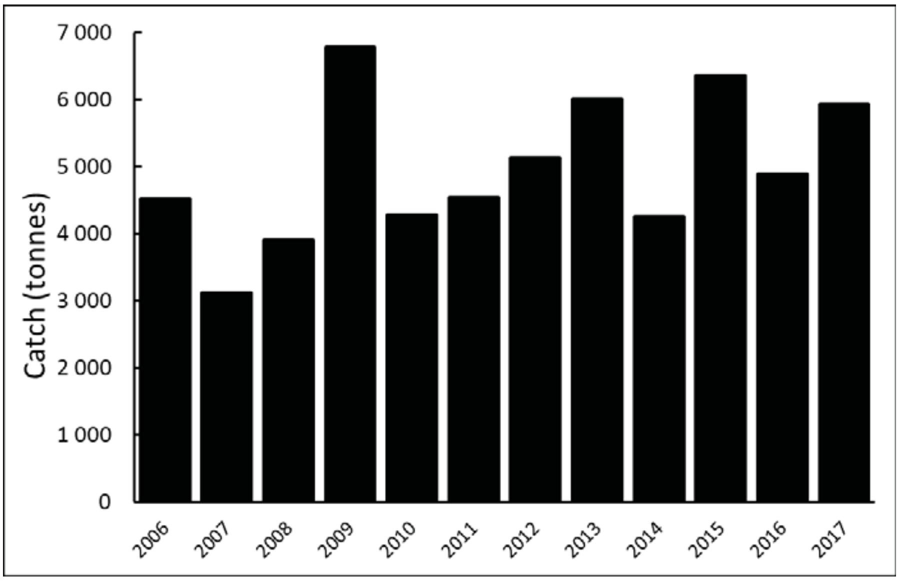
vessels and fishing effort. Considerable effort has been expended to assess the orange roughy stocks in the Indian Ocean, with a provisional assessment on the Walter's Shoal Region stock undertaken in 2018 (SIOFA, 2018b). Some seven other stock areas have been identified in the southern Indian Ocean and biological data has been collected for many of these, along with information from acoustic surveys. Current estimates are that stock in the Walter's Shoal Region is at 50 percent of the virgin stock levels (SIOFA, 2018b). Assessments have not been performed for other orange roughy stocks or other fish species.

FIGURE 13.13
Annual catches of orange roughy between 2006 and 2015 by SIOFA members



Source: SIOFA, 2018b, 2019.

FIGURE 13.14
Annual catches of alfonsino between 2006 and 2015 by SIOFA members



Source: SIOFA, 2018b, 2019.

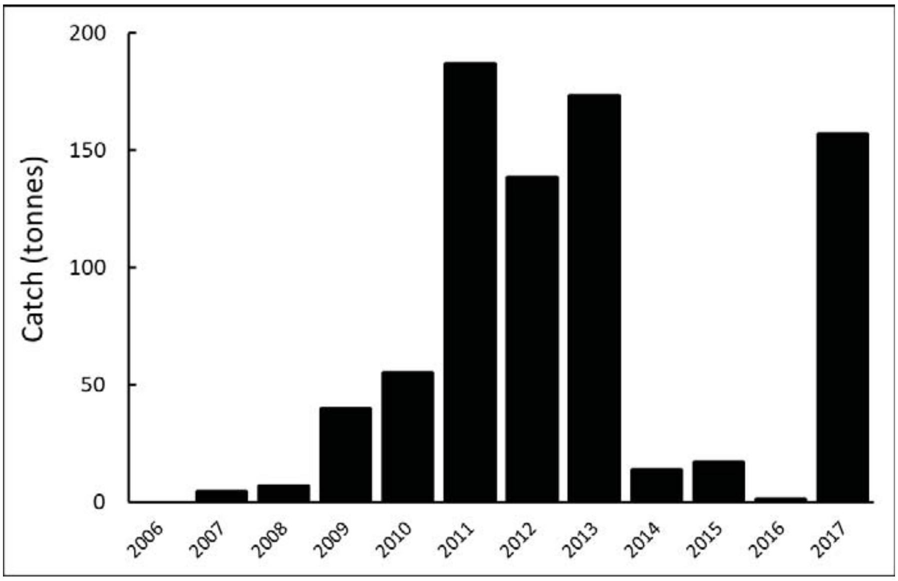
Minor commercial species and bycatch species vary widely and have only been fully recorded in a few cases. In general, the main target species is orange roughy with bottom trawls, and alfonsino and Pacific amourhead with deep midwater trawls. Other minor target species include oreo dories, rubyfish, butterfish and cardinalfish. The bycatch in these fisheries appears to be very low, mainly because the trawls target aggregations that can be identified by experienced vessel masters (SIOFA, 2018b).

Australia has undertaken both trawling and longlines within the high seas of the Indian Ocean, but does not specify the areas fished. The trawl catch composition varies greatly: alfonsino, orange roughy, ocean blue-eye trevalla, blue-eye trevalla and mixed rubyfish form important components of the catch in various years from 2005–2016. Longline catches occurred in 2008 and 2015–2016 targeting hapuku and other species; in 2015 these were almost entirely shortnose spurdog, which were discarded (SIOFA, 2018b).

The extreme south

A limited amount of longlining for Patagonian toothfish occurs in the extreme south of the region on the southern part of the Southwest Indian Ridge, and further south around Del Cano Rise, conducted by vessels under the flag of the French *Territoire des Terres australes et antarctiques françaises*, as well as Spain, Republic of Korea and Japan. The French territories have fished primarily in the EEZs around Kerguelen or Crozet but have sometimes set gear within the high seas of what is now the SIOFA area, while in transit to La Réunion, their port of landing. Between one and three vessels have been involved each year since 2006, fishing for between 13 and 40 days, taking 11–22 tonnes of toothfish, plus 31–69 tonnes of other species annually (SIOFA, 2018b). Longliners from the Republic of Korea intermittently engaged in similar fishing from 1999 to 2013. Spain fishes with longlines at many locations in the Indian Ocean, including in the far south where they fished from 2003 to 2006 and again in 2017. The toothfish longliners take a secondary catch of grenadiers and blue antimora. Total high seas catches of Patagonian toothfish are small, amounting to around 160 tonnes in some years, though total catches from non-contracting parties may increase this value slightly (Figure 13.15).

FIGURE 13.15
Annual catches of Patagonian toothfish between 2006 and 2015 by SIOFA members



Source: SIOFA, 2018b, 2019.

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14. Southern Ocean

FAO Major Fishing Areas 48, 58 and 88

SUMMARY

The Southern Ocean is an uninterrupted circum-global expanse of sea around Antarctica formed by the southern extensions of the Pacific, Atlantic and Indian Oceans. The continental shelf around Antarctica is deeper than seen elsewhere and covered in sea ice during the winter period. Several islands are situated at the northern limit of the Southern Ocean and the waters adjacent to these are under national management regimes. There are no EEZ waters south of 60° S, and all can here be regarded as high seas. This chapter includes more information on the fisheries in the national waters around the islands than has been included in other chapters.

The harvested resources of the Southern Ocean have an unfortunate history of over-exploitation that includes: fur seals and baleen whales in the 1900s, and more recently the nototheniid rockfish in the 1980s. Though scientific information was invariably lacking to manage these species, there was also a lack of functioning infrastructure to agree upon and implement management strategies. The International Whaling Commission entered into force in 1946 and in many respects paved the way for the later RFMO/As dealing with conventional fisheries. The *Convention on the Conservation of Antarctic Marine Living Resources* (CAMLR Convention) entered into force in 1980 and focused mainly on the collapsed rockcod fisheries around the northern islands and the potential ecological impacts of a developing krill fishery. A series of directed fishing bans followed, alongside measures to protects various components of the wider ecosystem such as seabirds and benthic habitats, including a general ban on exploratory toothfish fishing in waters shallower than 550 m to protect benthic habitats. The toothfish fisheries, which were initially exploited by bottom trawls, saw the development of a deeper longline fishery that largely replaced the trawl fishery in all but one area, and has been subject to strict controls to avoid over-exploitation. Commercial bottom trawling and gillnetting are not currently permitted in high seas areas. CCAMLR have operated a policy of not allowing its fisheries to develop faster than the knowledge required to manage them. The high seas bottom fisheries are now exclusively fished with longlines as exploratory fisheries: this means that states, vessel access and allowable catch are all closely controlled.

The only bottom resource fished in the high seas is the Patagonian toothfish that is more abundant in the northern part of the Southern Ocean, and the Antarctic toothfish that occurs around Antarctica itself. The catches have been relatively stable over the past ten years or so and though IUU fishing still occurs, it has largely been controlled through a variety of measures and stronger enforcement. Catches taken by bottom fishing gears in the high seas, all by longlines and mainly south of 60° S, amounted to 4 408 tonnes in the 2015/16 season – almost all of these were Antarctic toothfish with some Patagonian toothfish and grenadiers (Table 14.1).[1] By contrast, the 2015/16 season catches by bottom gears in the areas adjacent to the islands under national control, all of which are in the north of the Southern Ocean, totalled 14 046 tonnes; of which

[1] A CCAMLR fishing season is from 1 December to 30 November, for example, 1 December 2015 to 30 November 2016. Following CCAMLR practice, this example would be here referred to as the 2015/16 season or simply as 2016 (since most of the catch is in the second year of the season).

TABLE 14.1
High seas[1] bottom fisheries catch in the Southern Ocean in the 2015/16 season

Gear	Ground	Flag states	Species	Catch 2016[2] (tonnes)
Longline[3]	Ross Sea and others	At least six different flags	Antarctic toothfish	4 105
			Patagonian toothfish	61
			grenadiers	201
			others	41
TOTAL				4 408

[1] The high seas catches are from areas 48.1, 48.2, 48.5, 48.6, 58.4.1, 58.4.2, 58.4.3a,b, 58.4.4a,b, 88.1, 88.2, 88.3. Catches around the sub-Antarctic islands have been excluded.

[2] 1 December 2015–30 Nov 2016 or the 2015/16 season.

[3] No recorded catches using bottom trawls or pots, which are not permitted in the high seas commercial fishery.

Source: CCAMLR, 2018a.

around 11 939 tonnes (85 percent) was Patagonian toothfish. Longlines accounted for 10 984 tonnes (92 percent) of the Patagonian toothfish catch and bottom deployed otter trawls the remaining 955 tonnes (8 percent). The change to Patagonian toothfish catch reflects their more northern distribution compared to Antarctic toothfish. Patagonian toothfish are caught throughout the year, whereas owing to ice cover, Antarctic toothfish are caught during December–April.

GEOGRAPHIC DESCRIPTION

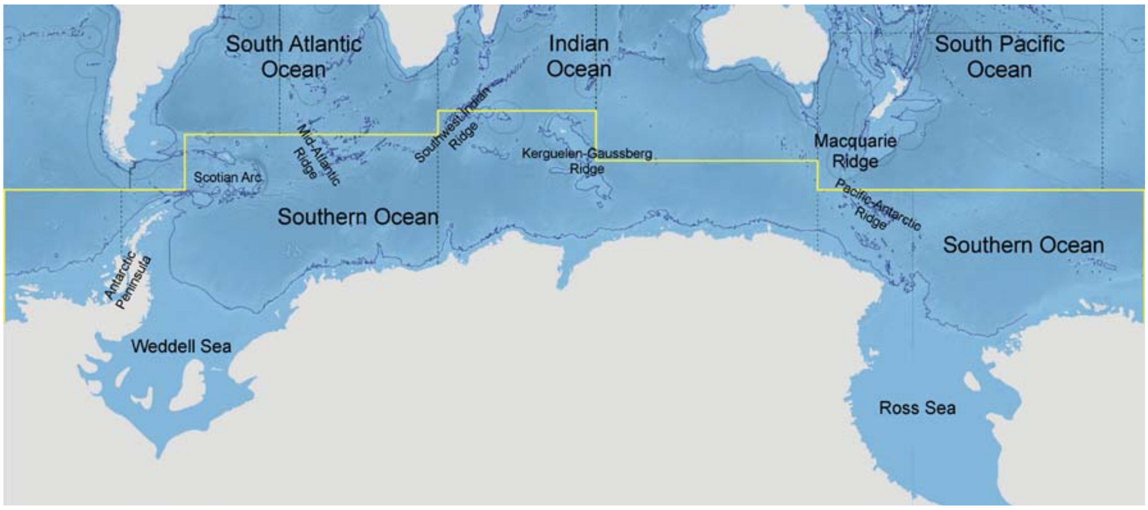
The Southern Ocean comprises southern extensions of the South Pacific, South Atlantic and Indian Oceans, and forms an almost uninterrupted circumglobal belt of open ocean. This is at its widest just south of the extremities of Africa and Australasia at around 3 500 km, and at its narrowest south of South America at less than 1 000 km (Figure 14.1). The Antarctica continental shelf is mostly narrow, and widens only around the Antarctic Peninsula, Ross Sea and Weddell Sea, though much of the latter two seas are covered by “ice shelves”. The continental shelf around Antarctica is deep and averages around 500 m in depth, whereas the continental shelves in other regions are much shallower and have their outer margins at around 200 m in depth. Oceanographically and biogeographically, the belt of open ocean is divided in two by the Antarctic Convergence (or Antarctic Polar Front), where cold southern water passes beneath the warmer subtropical gyres of the Pacific, Atlantic and Indian Oceans, flowing on to feed deep, sub-surface layers further north (Figure 14.2). The latitude of the Convergence varies both temporally and with longitude, but an approximation is used for fisheries management and to define the limits of the Southern Ocean. It comprises nearly 10 percent of the surface area of the World Ocean and includes nearly 15 percent of the World’s high seas. Almost all of it is open ocean, through most of the region’s fisheries have occurred close to coastlines (Table 14.2).

Sea ice cover is at its lowest in summer, in February, when much of the continent’s shoreline (whether composed of rock or land ice) is surrounded by light ice, at most – the principal exception being the Weddell Sea. The winter sea ice maximum is in

TABLE 14.2
Area statistics for the Southern Ocean

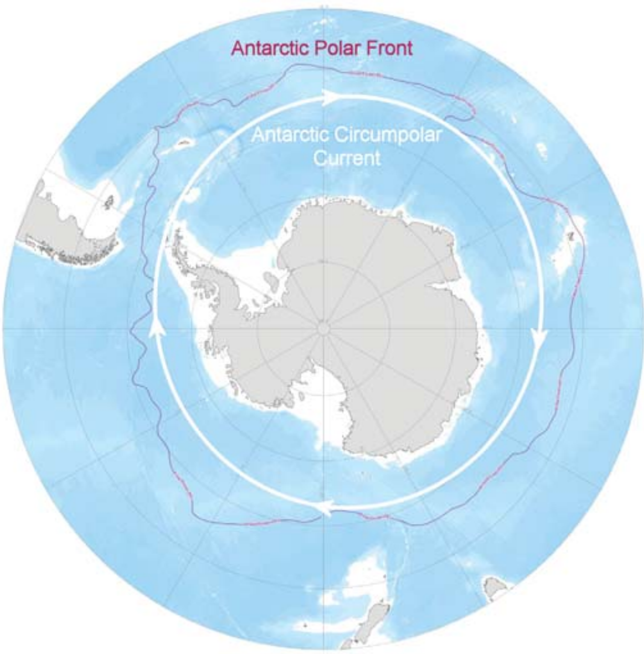
Geographical area	Surface area (km²)
Total sea area	35 680 000
Area of high seas	32 654 000
Area of high seas shallower than 200 m	180 000
Area of high seas shallower than 400 m	948 000
Area of high seas shallower than 1 000 m	2 761 000
Area of high seas shallower than 2 000 m	2 975 000

FIGURE 14.1
Map of the Southern Ocean showing the northern limit of the CCAMLR convention area (yellow line)



200 nautical mile arcs, 2 000 m isobath (GEBCO), FAO fishing areas.
Source: FAO VME Database, Mercator projection.

FIGURE 14.2
Principal currents of the Southern Ocean

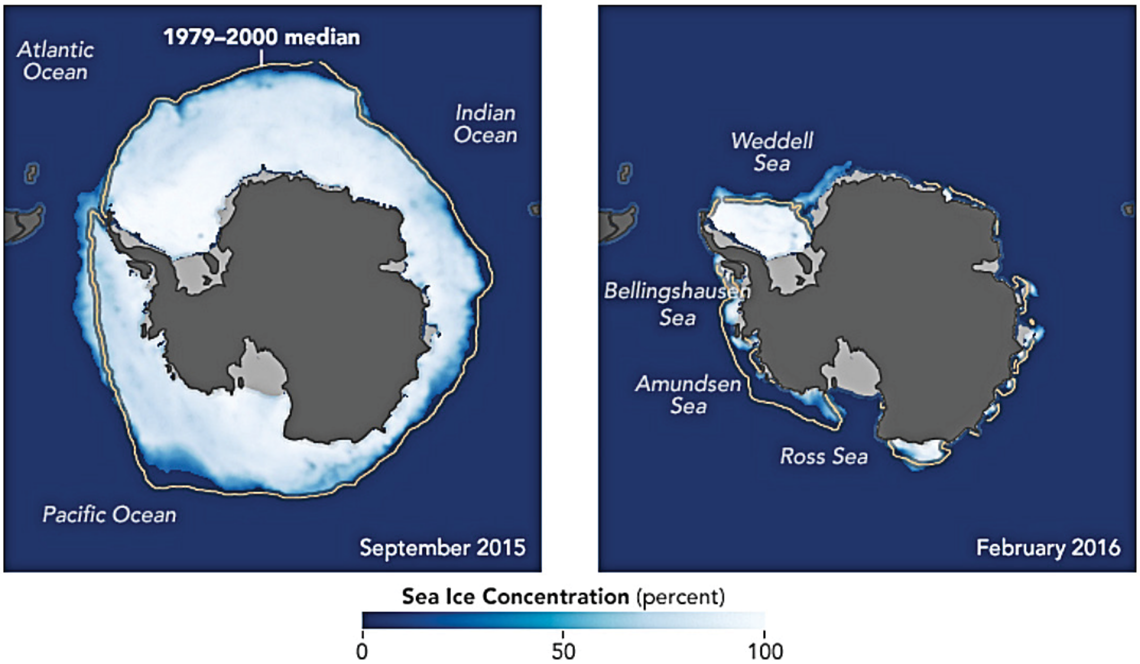


Antarctic circumpolar current is shown diagrammatically.
Source: CCAMLR GIS, https://gis.ccamlr.org/

September when heavy ice extends to 60–65° S (Figure 14.3; Parkinson and Cavalieri, 2012). The extent of winter sea ice cover has increased in recent decades, as seen in 2014.[2] Overall however, average Antarctic temperatures are actually on the increase,

[2] https://www.nasa.gov/content/goddard/antarctic-sea-ice-reaches-new-record-maximum

FIGURE 14.3
The extent of the sea ice around Antarctica at its maximum (September 2015) and minimum (February 2016) coverage



Source: https://earthobservatory.nasa.gov/WorldOfChange/sea_ice_south.php

causing large icebergs to split from the ice shelf, as was the case of the Larsen C iceberg in 2017.[3]

North of the Antarctic shelf break and continental slope, the Southern Ocean's seabed is mostly at abyssal depths, far beyond the reach of bottom fisheries. There are several ridges and many of these bare islands. Most areas of seabed at potentially-fishable depths are small- to moderate-sized patches scattered along the ridges and around the islands, though both the Kerguelen Plateau (around Kerguelen and Heard Islands) and an area immediately south of it are extensive.[4] Otherwise, there are small pockets of seabed shallower than 2 000 m in various isolated locations (Figure 14.4).

Both the human and political geography of the region are as unique as its physical geomorphology. Neither the Antarctic nor any of the sub-Antarctic islands have any permanent human inhabitants, only itinerant workers, many of whom are scientists; there is therefore almost no market for local seafood. Meanwhile, all of the region's potential fishing grounds lie far from any practical landing port. As a consequence, all the fisheries have much of the character of distant-water operations, even those which work within sight of land or in the EEZ of the vessel's flag state.

As to political boundaries, all waters and lands south of 60° S (including the South Orkneys, South Shetlands, the Balleny group and Scott Island, as well as the continent itself) are subject to the Antarctic Treaty of 1959 (in force since 1961). As a result, the high seas is normally accepted as extending to all coastlines south of 60° S. By contrast, the sub-Antarctic islands lying north of the Treaty's area of application are under national sovereignty. Most of the sub-Antarctic islands are surrounded by EEZs,

[3] https://www.ccamlr.org/en/news/2017/ccamlr-provides-special-protection-marine-area-exposed-giant-larsen-c-iceberg

[4] The name "Kerguelen Plateau" is sometimes used for the entire Kerguelen–Gaussberg Ridge by geomorphologists. The "Plateau" of the fisheries literature is a much smaller (if still large) feature.

FIGURE 14.4
Areas of seabed at potentially fishable depth

Blue line = 2 000 m depth contour.
Red lines = potentially fishable areas.
Key: (1) Kerguelen Plateau (around Kerguelen and Heard islands), (2) On and near the Scotian Arc, (3). scatter of small patches (on the flanks and summits of seamounts) where the mid-ocean ridge passes through the region's Atlantic sector (at 10° W–30° E), (4). scatter on the Southwest Indian Ridge (at 30°–40° E, (5). Around the sub-Antarctic islands of the Indian Ocean sector, (6). some seamounts further south, of which Lena Seamount, (7). two relatively large patches on the Kerguelen–Gaussberg Ridge, (8). scatter of small patches where the Macquarie Ridge intersects the Pacific-Antarctic Ridge and extending from there towards the Ross Sea.
Source: FAO VME Database, South Polar projection, locations added.

though Bouvet is encircled only by a Territorial Sea. National maritime jurisdiction extends south of 60° S wherever the boundary of an EEZ around an island lying further north cuts across that parallel.[5]

ECOSYSTEMS AND RESOURCE SPECIES

When summed across the vast extent of the region's productive waters, the ecosystems of the Southern Ocean are among the world's richest, though their productivity per unit area is not exceptionally high. It is spatially variable: the "Scotia Sea", east and

[5] "A dispute exists between the Governments of Argentina and the United Kingdom of Great Britain and Northern Ireland concerning sovereignty over the Falkland Islands (Malvinas)" - see United Nations document ST/CS/SER.A/42.

northeast of the Antarctic Peninsula, has proven particularly productive since the era of fur-seal hunting, through to the whaling off South Georgia and into the modern fisheries era. Thus, during the first 14 years of commercial-scale fishing (1969–1992), reported catches from the Atlantic sector (FAO Major Fishing Area 48) amounted to nearly 2 100 000 tonnes (1 700 000 tonnes from around South Georgia alone), whereas the Indian Ocean sector (Area 58) yielded just 920 000 tonnes, of which 870 000 tonnes was from around Kerguelen. The region's Pacific sector (Area 88) produced almost no catch at all at that time (Ainley and Blight, 2008).

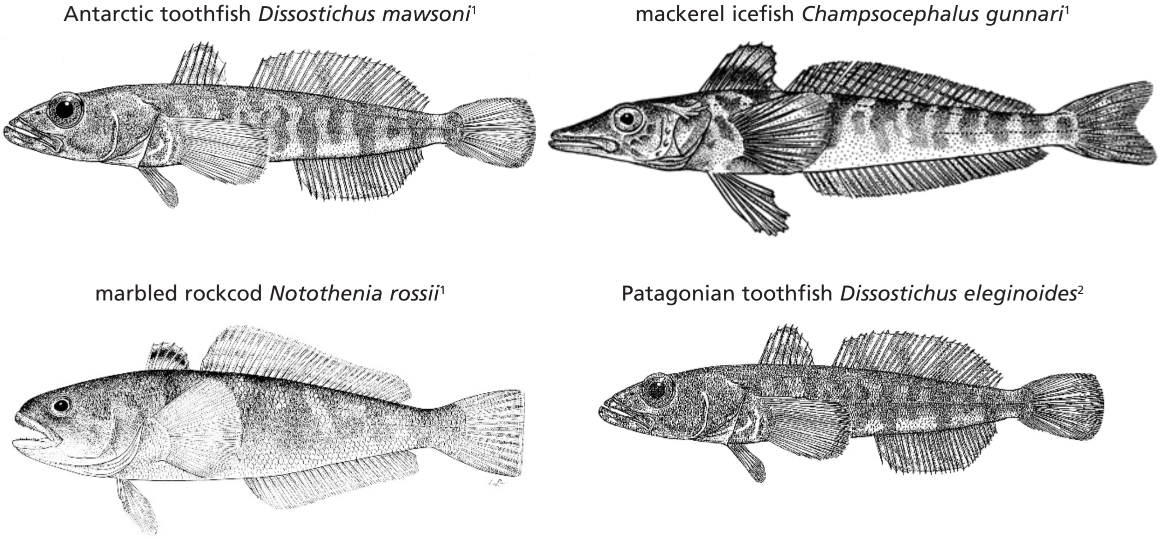
The foundation of ecosystems is not fundamentally different from what is seen in cold-temperate areas in the Northern Hemisphere, with brief but rich blooms of phytoplankton at the surface and a downward flux of material and energy, largely through the migration of herbivores and their predators. The compositions and structures of the southern ecosystems are, however, more unique. The primary planktonic herbivores are euphausiid krill (especially the large, and comparatively long-lived, Antarctic krill), rather than calanoid copepods as would be more typical in the north. The krill formerly supported high biomasses of baleen whales and continue to support large numbers of seals and marine birds with the region's avifauna being notably rich and diverse. Annual krill consumption has been estimated at 43 000 000 tonnes by baleen whales, 128 000 000 tonnes by seals, 33 000 000 tonnes by birds, 100 000 000 tonnes by squids, plus more eaten by fish (Hewitt *et al*., 2008). It is the high krill production, itself a consequence of interactions between the Antarctic Circumpolar Current and seabed topography, that supports the richness of the Scotia Sea (Trathan *et al*., 2014). Fish are diverse at the species level but are drawn from only a few taxonomic families, which have adapted to the extreme conditions, the icefish (Nototheniidae) being especially prominent. Food chains tend to be very short, most obviously so in the case of the once-prominent phytoplankton–krill–baleen whale chain. Some of the commercially exploited finfish are likewise predators of krill, though others feed one trophic level higher (Xavier and Peck, 2015).

The Southern Ocean is cold, with summer surface temperatures of 4–8 °C at the Convergence, while they are sub-zero year-round near the continent and its ice. Deep bottom waters, formed by downwelling at the ice edge, are also very cold, such that the continental slope of Antarctica is washed by sub-zero water. Below the Convergence, temperatures at fishable depths above 2 000 m are a few degrees above zero but the isotherms rise towards the Antarctic Divergence, located at the surface around 50° S, in the Atlantic sector, or at 60° S elsewhere (Knox, 2007; Williams, 2015). While those low temperatures do not directly affect the warm-blooded marine mammals and birds, except insofar as their energy-intake requirements are increased, the metabolisms of fish and squid are slowed, reducing the annual productivity at higher trophic levels. Species can achieve high biomasses through extended life expectancies, rather than high turnover rates, which makes them less resilient to excessive fishing pressure than would occur in more temperate seas. Several different benthic fish species are targeted commercially (Figure 14.5).

There has been a long series of severe depletions of higher-level predators in the Southern Ocean, beginning two centuries ago with fur seals, continuing through baleen whales and, more recently, many finfish species through to the 1980s. While the full consequences remain matters of debate, it appears that there have been substantial impacts on ecosystem structure (e.g. Ainley and Blight, 2008). Hence, modern fisheries in the region exploit a perturbed system, as do those in other regions.

There were formerly extensive fisheries for several species; these included bottom fisheries for notothenid rockcods – especially marbled rockcod, which was found in relatively shallow water around some of the sub-Antarctic islands – southern analogues to the gadoids and merluccids of more northerly areas.

FIGURE 14.5
Principal demersal resource species of the Southern Ocean



Source:
[1] Food and Agriculture Organization of the United Nations, Original Scientific Illustrations Archive.
[2] Fischer and Hureau (1985).

Mackerel icefish were fished on the bottom but now primarily harvested by midwater gear and exclusively so in the high seas. Icefish, members of the Channichthyidae, are notable for having no haemoglobin. They prey on krill and are primarily found around the sub-Antarctic islands at depths of less than 400 m, where they are eaten by fur seals, albatrosses and penguins in particular. Of importance to fisheries conservation, the species has a high, though highly variable, natural mortality rate, as well as high inter-annual variability in recruitment (Kock *et al*., 2007; Hewitt *et al*., 2008). Strictly pelagic fisheries have exploited myctophid lanternfishes and krill, while there was formerly some crabbing.

The only species currently targeted by bottom fishing in the high seas of the region are toothfish: primarily Patagonian toothfish around the sub-Antarctic islands and Antarctic toothfish further south, including around the continent itself, though the ranges of the two overlap broadly. Those ranges are circum-global at their preferred latitudes, though the Patagonian toothfish also extends much further north on the continental slopes of South America. Individuals of either species can exceed 2 m in length and 200 kg in weight, while reaching ages of several decades. Following a planktonic larval phase, Patagonian toothfish settle to the seabed in relatively shallow water, moving deeper as they grow, the adults usually living at depths of 500–2 500 m, where they are opportunistic carnivores feeding on fish, crustaceans and squid (Collins *et al*., 2010). Antarctic toothfish are less well known, though research is proceeding (Hanchet *et al*., 2015).

MANAGEMENT OF HIGH SEAS BOTTOM FISHERIES

Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)

CAMLR Convention

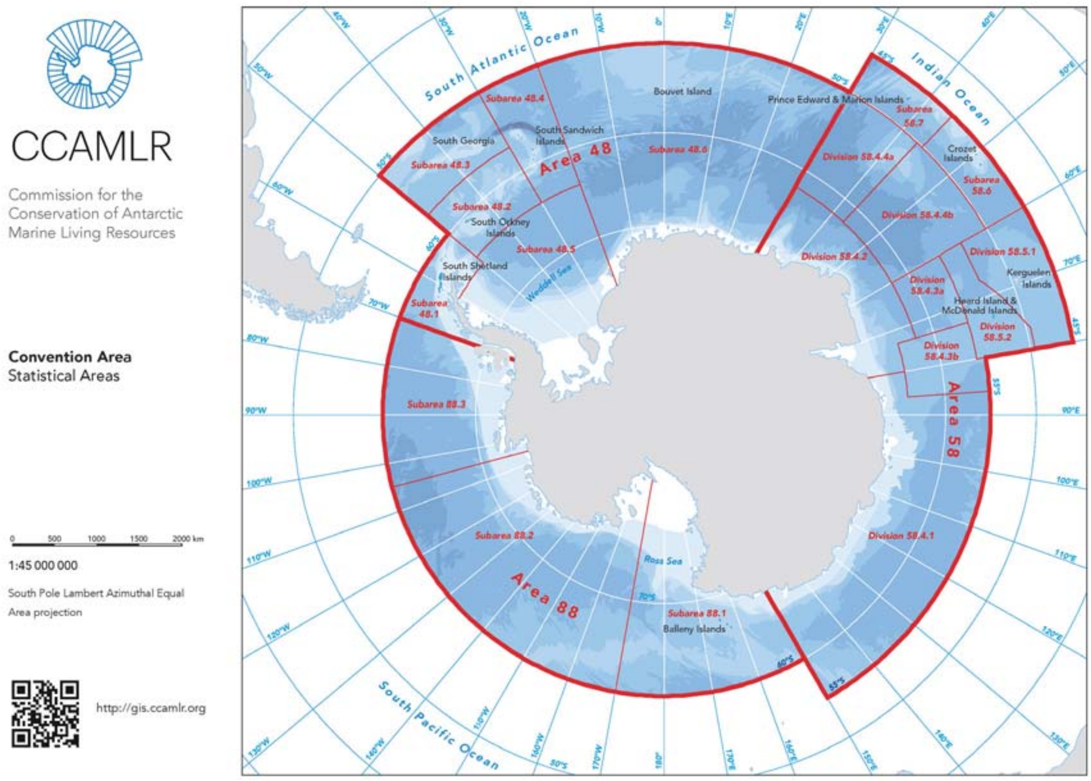
The international management regime of the CAMLR Convention, owing to the provisions of the Antarctic Treaty and its wider Antarctic Treaty System, is broader in the Southern Ocean than its equivalents in other regions. It includes all species of Antarctic marine life: finfish, molluscs, crustaceans and all other species of living organisms – including birds – found south of the Antarctic Convergence. However, the management of marine mammals is under the International Convention for the Regulation of Whaling and the Convention for the Conservation of Antarctic Seals.

The safeguarding of the resources of the Southern Ocean was a priority and lead to the Conference on the Conservation of Antarctic Marine Living Resources in 1980 and the signing of the Convention on the Conservation of Antarctic Marine Living Resources (CAMLR Convention). That Convention, which established the CAMLR Commission (CCAMLR), entered into force two years later. As of 2019, CCAMLR has 25 Members and 11 acceding States.

The Convention's stated objective is "the conservation of Antarctic marine living resources" and includes "rational use" such as harvesting. Limits on fishing are firmly defined: No harvested population may be reduced "to levels below those which ensure its stable recruitment", nor "below a level close to that which ensures the greatest net annual increment", while those previously depleted below such levels must be rebuilt. The "ecological relationships between harvested, dependent and related populations" are to be maintained and, "the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades" is to be minimized. Maintaining ecological relationships does not feature so strongly in the equivalent Conventions and Agreements of the fisheries bodies in the other regions, where they tend to focus more on the protection of the marine environment from any harmful impacts caused by fishing.

The CCAMLR convention area encompasses the marine waters – including nearshore waters – south of the Antarctic Convergence, which is deemed to follow the boundary given in the convention (Figure 14.6). The convention area thus extends

FIGURE 14.6
Map of CCAMLR convention area showing statistical areas



Source: http://gis.ccamlr.org

beyond the Treaty area. Those states which have declared EEZs, Territorial Seas, or other forms of national maritime jurisdiction over waters around sub-Antarctic islands are all Members of CCAMLR, but retain the option of either applying each international conservation measure within the areas under their jurisdiction or else formally rejecting such application.

Fisheries development

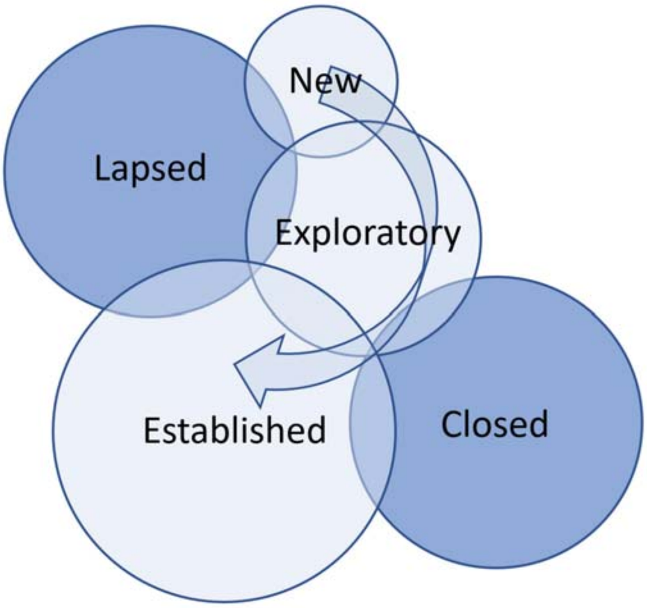
With the Southern Ocean's long history of swift over-development of resource exploitation, CCAMLR paid close attention to the management of severely over-exploited and new (or exploratory) fisheries, at a time when most RFMOs and national fisheries agencies were still focused on fishing long-established stocks. CCAMLR's intention has been to prevent new fisheries from emerging faster than they are able to manage them, while they also rely on the fisheries to generate the information needed for their management (Miller *et al*., 2005; Kock *et al*., 2007).

As early as 1991, the commission required prior notification of proposed new fisheries, with the proponent providing information essential to management (CM 31/X). The requirements have since been elaborated on considerably, while a distinction has been drawn between "new fisheries" – for which key information has not previously been submitted to CCAMLR – and "exploratory fisheries", which include those no longer "new" but still with insufficient information for scientific assessment, including an assessment of impacts on dependent species. Besides complying with a Fishery Operations Plan (prepared by the proponent) and a Data Collection Plan (prepared by the scientific committee), exploratory fisheries are subject to administrative cost-recovery payments (CM 21-01 and 21-02). For the toothfish fisheries, which are the only ones currently operational, there are the additional fishery-specific requirements noted above, some of which include the direction of exploratory effort into defined "research blocks" from which data are desired, while catch limits are restricted to levels that permit such data collection (CM 41-01–41-11). Research fishing, designed to acquire information to support the management of all stages of a fishery, is also promoted by CCAMLR (CM 24-01). The combination of measures provides science-based management at as detailed a level as any multilateral system has attempted. Those fisheries which proceed beyond the "exploratory" phase can be re-designated as "established". Others are designated as "lapsed fisheries", if commercial activity and scientific assessments have ceased, or "closed fisheries" if directed fishing for the target species has been prohibited (Figure 14.7).

Fisheries and resource management

Based on scientific advice CCAMLR set minimum mesh sizes immediately, and during the 1985–1990 period introduced various closures, prohibitions to directed fishing, and total catch limits around South Georgia, South Orkneys and the Peninsula for rockcod and other finfish (Figure 14.8; Table 14.3). Over the next ten years these measures continued, as well as additional ones adopted to limit fisheries in other areas or on other species, or to permit fisheries for certain species in certain areas. In 1997, a more general measure was adopted on toothfish to prohibit directed fishing in all statistical areas within the convention area, except where specific measures allowed fishing (CM 120/XVI). However, this was not designed to prohibit fishing *per se*, but to permit controlled exploratory fishing in areas where there was no previous history of similar fisheries or where the knowledge was insufficient to manage the stock. Catch limits on exploratory fisheries can range from tens to thousands of tonnes. In 1997 there were applications from Contracting Parties to conduct exploratory toothfish fisheries in all areas excepting 48.5, 58.4.2 and 58.4.1. These exploratory fisheries were each controlled by a conservation measure allowing specified contracting parties to catch up to a specified amount, under strict monitoring and data collection requirements,

FIGURE 14.7
CCAMLR regulatory framework for managing commercial fisheries



Source: Re-drawn from www.ccamlr.org

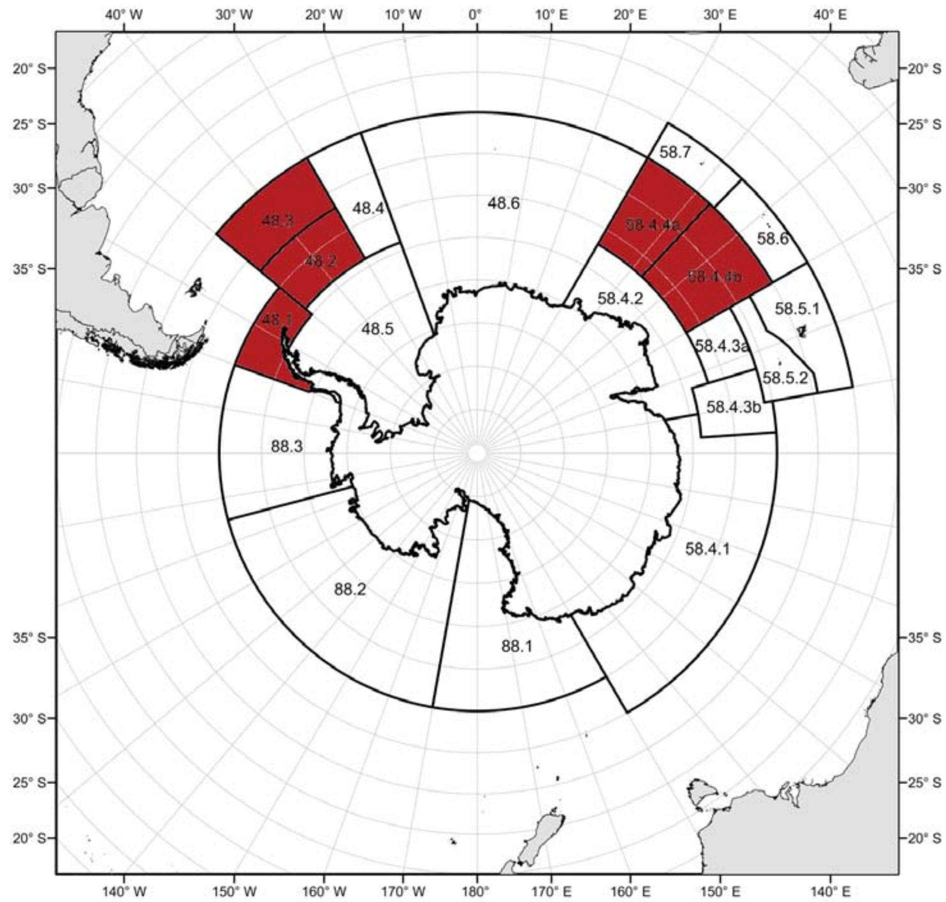
TABLE 14.3
Initial measures introduced by CCAMLR in 1985–1990 to control fishing on over-exploited stocks of rockcod and other species

Area	Year introduced	measure	Detail
48.3	1984	1/III	Closure of waters adjacent to South Georgia Fishing prohibited within 12 nautical miles.
48.3	1985	3/IV	Prohibition of Directed Fishery on *Notothenia rossii* around South Georgia
48.1	1986	5/V	Prohibition of Directed Fishery on *Notothenia rossii* in the Peninsula Area
48.2	1986	6/V	Prohibition of Directed Fishery on *Notothenia rossii* around South Orkneys
48.3	1987	8/VI	Limitation of the Total Catch of *Champsocephalus gunnari* in Statistical Subarea 48.3, After such time as that total catch has been reached *C gunnari*, *Notothenia rossii*, *Notothenia gibberifrons*, *Chaenocephalus aceratus* and *Pseudochaenichthys georgianus* shall not be taken in Subarea 48.3
		10/VI	Prohibition of Directed Fishery on *Champsocephalus gunnari* in Statistical Subarea 48.3 from 1 April until 1 October 1988. During the protected period *C. gunnari*, *Notothenia rossii*, *Notothenia gibberifrons*, *Chaenocephalus aceratus* and *Pseudochaenichthys georgianus* shall not be taken in Statistical Subarea 48.3
		20/IX	Modified to TAC on *C. gunnari* and bycatch limits CM 20/IX (1990)
58.4	1990	28/IX	Limitation of the total catch *Notothenia squamiyrons* in statistical sub area 58.4 in the 1990/91 season
48.1, 48.2	1990	27/IX	Prohibition of directed fishing for finfish in statistical subareas 48.1 and 48.2 in the 1990/91 season (see Figure 14.7)

Source: https://www.ccamlr.org/en/conservation-and-management/conservation-and-managment

FIGURE 14.8

Areas where measures restricting the catch of rockcod species were in forced, 1984–1987 (48.1, 48.2, 48.3) and from 1990 (54.4.4a,b)



These or similar measures are still in place in these areas.

Source: CCAMLR, https://www.ccamlr.org/en/system/files/e-schedule2018-19_0.pdf

as specified in the individual measures (CM 21-01). The exploratory fisheries are conducted by commercial vessels designed to take representative samples in Small Scale Research Units (SSRUs) that cover a range of depths in order to collect information that would enable the development of a sustainable commercial fishery, if suitable. The number of SSRU areas required to be fished was increased in 2016 to allow for better coverage (CM 41-01). This proactive use of commercial vessels to provide information on abundance and distribution according to a rigorous scientific design, under strictly controlled conditions, is unique to the Southern Ocean.

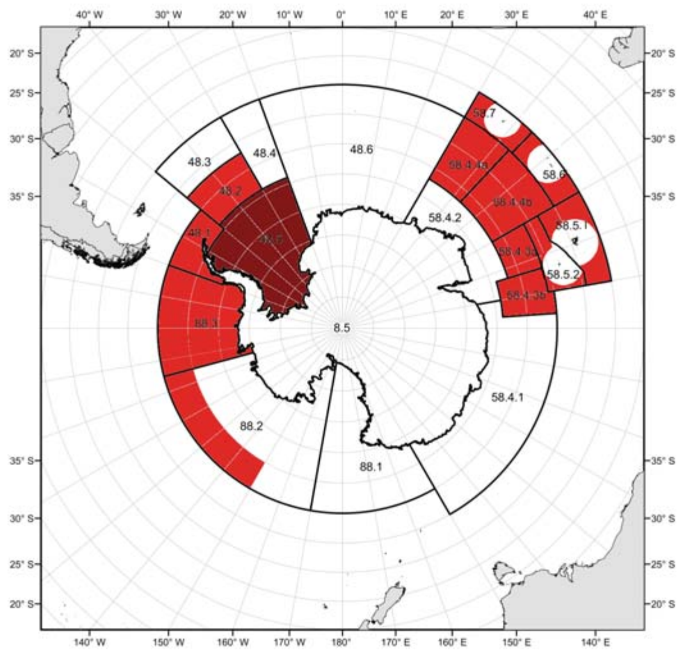
The areas where directed fishing is currently permitted or prohibited are stipulated by CM 32-02 and, except for the toothfish restrictions, are similar to that adopted in the 1990s. Areas fished as exploratory fisheries are not included in this measure. The general ban on bottom trawls and gillnets has rendered most of these benthic species effectively unfishable. A summary of the prohibitions first introduced in 2012 and currently in effect are shown in Figure 14.9, while Figure 14.10 provides a summary of the current permitted toothfish areas. Under the CCAMLR management system, the extant toothfish fishing activity is classified into five established, seven exploratory and one research fisheries (Figure 14.7). In other regions, this review ignores fishing undertaken as scientific research and scientific surveys, but the CCAMLR approach differs because research fishing is undertaken by commercial vessels following

FIGURE 14.9
CCAMLR prohibitions on directed fishing in force for the 2017/18 fishing season in the Southern Ocean (a) for listed species under CM 32-02(2017), and (b) for toothfish species under CM 32-02(2017)[1] (red) and CM 32-09(2018) (dark red)

Area \ Taxon	Blackfin icefish *Chaenocephalus aceratus*	Patagonian toothfish *Dissostichus eleginoides*	Toothfish spp. *Dissostichus spp.*	Lanternfish *Electrona carlsbergi*	Humped rockcod *Gobionotothen gibberifrons*	Grey rockcod *Lepidonotothen squamifrons*	Marbled rockcod *Notothenia rossii*	Yellowfin notothen *Patagonotothen guntheri*	South Georgia icefish *Pseudochaenichthys georgianus*	All other species of finfish
Subarea 48.1	1,2	1,2	1,2	1,2	1,2	1,2	1,2,4	1,2	1,2	1,2
Subarea 48.2	1,2	1,2	1,2	1,2	1,2	1,2	1,2,4	1,2	1,2	1,2
Subarea 48.3	3			1,2	3	3	4	3	3	
Division 58.4.4a			1,2,5			1,2,5				
Division 58.4.4b			1,2			1,2				
Division 58.5.1		1,2,6								
Division 58.5.2 east of 79°20'E and outside the EEZ to the west of 79°20'E		1,2								
Subarea 58.6		1,2,5,6								
Subarea 58.7		1,2,5								
Subarea 88.2 north of 65°S except for SSRUs 882A–B			1,2							
Subarea 88.3			1,2							

[1] See measure for conditions attached to these restrictions.

(a)



(b)

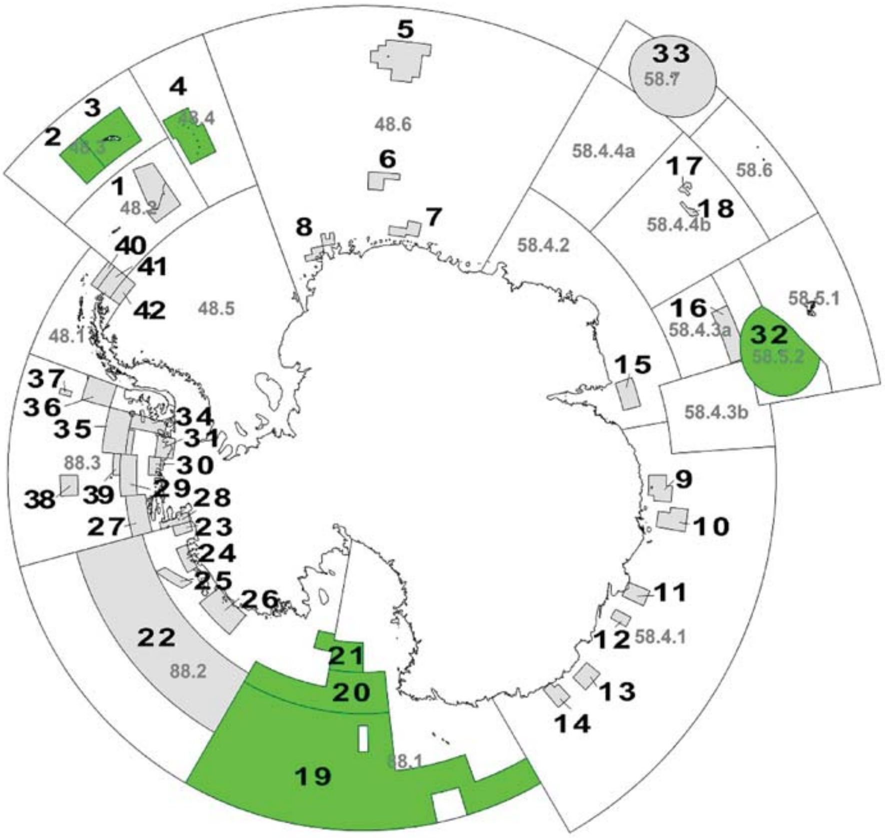
Source: CCAMLR, https://www.ccamlr.org/en/system/files/e-schedule2018-19_0.pdf

a carefully designed programme employing CCAMLR measures and sampling protocols. The control of commercial fishing operations, and the use of exploratory fishing as part of a research programme in the high seas, on such a fine spatial scale, is unique to the CCAMLR system of management.

Although some toothfish were taken as bycatch in very early bottom trawl fisheries, the main fishery started with the introduction of longlining in 1989 at South Georgia. Some trawling for toothfish continued in other areas, but from the early 1990s longlining was the predominant fishing method. By 2003 the use of bottom trawls

FIGURE 14.10

Map of the CCAMLR convention area showing areas with toothfish catch limits in place or areas with proposed research fishing



ID	Area code
1	48.2
2	48.3 B
3	48.3 C
4	48.4
5	48.6_2
6	48.6_3
7	48.6_4
8	48.6_5
9	58.4.1_1
10	58.4.1_2
11	58.4.1_3
12	58.4.1_4
13	58.4.1_5
14	58.4.1_6
15	58.4.2_1
16	58.4.3a_1
17	58.4.4b_1
18	58.4.4b_2
19	RSR North 70
20	RSR South 70
21	RSR SRZ
22	88.2 H
23	88.2_1
24	88.2_2
25	88.2_3
26	88.2_4
27	88.3_1
28	88.3_2
29	88.3_3
30	88.3_4
31	88.3_5
32	HIMI
33	PEI
34-39(P)	88.3
40(P)	48.1
41(P)	48.1
42(P)	48.1

Areas shown in green have catch limits set using integrated assessments.
Source: Figure 2 in CCAMLR, 2018e.

had been banned and the toothfish were all caught with bottom-set longlines and occasionally pots in some areas (notably around South Georgia). The only exception to the use of bottom trawls was in area 58.5.2 around Heard Island, where bottom trawls are still permitted – although longlining is now the predominant fishing method.

CCAMLR also moved to control fisheries by introducing gear-specific bans in some or all of their convention area. From 2006, bottom trawling was prohibited in all areas except where specifically permitted (CM 22-05). This effectively prohibited fishing on rockcod species. The use of gillnets was banned in all high seas areas in 2006.

The numerous conservation measures currently in force are varied.[6] In practice, restrictions on the region's demersal high seas commercial bottom fisheries have been reduced to longlining for toothfish, and include limitations to both specific areas (sometimes even to particular "small-scale research units") and to depths greater than 550 m in exploratory fisheries – the latter to protect benthic communities. Other restrictions vary among areas but can include catch limits, seasons, limits on bycatches of grenadiers and rajids (though at levels unlikely to be restrictive), with an accompanying "move-on" rule, in addition to requirements for research plans, data collection, observers, and the tagging and release of fish.

6 https://www.ccamlr.org/en/conservation-and-management/conservation-measures

Ecosystem approach to fisheries

With its broad remit and foundations in concerns over the impacts of the krill fishery, CCAMLR turned its attention to ecological relationships and the effects of fisheries on ecosystems early on. A CCAMLR Ecosystem Monitoring Programme, which monitored mammal and bird predators of krill, began as early as 1987. In 1990, the commission accepted its scientists' recommendation that krill management targets should allow for the ecological roles of the target species. CCAMLR utilises a more liberal application of precaution and the ecosystem approach, consistent with the objectives of its Convention and the Antarctic Treaty System more generally (Constable *et al.*, 2000; Miller *et al.*, 2005; Kock *et al.*, 2007; Agnew, 2008).

Following a considerable development process (Miller *et al.*, 2005), measures to reduce seabird mortality on longlines were introduced from the 1991/92 season (CM 29/X) – though the issue is primarily one of the sub-Antarctic EEZs rather than the high seas grounds around the continent, because of distances from island-breeding colonies. Restrictions on the generation of plastic waste aboard fishing vessels were added from 1993 (CM 63/XII). Prohibitions of various discharges from fishing vessels have since been added, including the discharge of whole fish (unless expected to survive) or processing offal when a vessel is south of 60° S (CM 26-01). The targeting of sharks was banned from 2006, while those caught incidentally are to be released alive when possible (CM 32-18). Following the UNGA resolutions, requirements for fishery assessments and a protocol for encounters with VME organisms were instituted from 2007 onwards (CM 22-06, 22-07 and 22-09; see Jones *et al.* (2016) for more detail on CCAMLR management of impacts on VME). Standards for ballast water exchange were added in 2008 (Recommendation 28/XXVII).

Since 1990, CCAMLR has had provisions for the protection of special areas, including monitoring sites, areas defined under the Protocol on Environmental Protection (Antarctic Specially Protected Areas and Antarctic Specially Managed Areas) and others. The latter include an area to the south of the South Orkneys that is deemed to have high conservation importance and was closed to commercial fishing from 2009 (CM 91-01 to CM 91-04). Even more recently, CCAMLR adopted the Ross Sea Region MPA which has a restricted multi-use harvesting plan (CM 91-05). Most recently, CCAMLR has urged consideration of climate change in its future activities (Recommendation 30/XXVIII).

Scientific support to management

As required by its Convention and where appropriate, CCAMLR bases its decisions on advice from its scientific committee, which draws on its working groups and subgroups. There are currently five such subsidiary groups:

- Working Group on Ecosystem Monitoring and Management (WG-EMM), which is mainly concerned with krill and predator–prey relationships;
- Working Group on Fish Stock Assessment (WG-FSA), which assesses resource status and the acquisition of data necessary for this;
- Working Group on Statistics, Assessment and Modelling (WG-SAM), which examines technical matters in stock assessment, as well as tagging programmes, estimation of IUU catches and methods for the assessment of bycatch species;
- Working Group on Incidental Mortality Associated with Fishing (WG-IMAF), primarily concerned with seabird mortality on longline gear; and
- Subgroup on Acoustics, Survey and Analysis Methods (SG-ASAM), which is focused on acoustic surveys of krill.
- The output of each informs the management of the region's fisheries but WG-FSA does so most directly.

Illegal, unreported and unregulated (IUU) fishing

The development of toothfish longlining was swiftly followed by the growth of a major IUU fishery, which did not employ the seabird-avoidance techniques used in the registered fishery and thus caused high bird mortality, besides its effects on the target resource. IUU activity, which began by 1993, was initially confined to the waters around South Georgia (as well as grounds outside the CCAMLR convention area) but moved to the Indian Ocean in 1996 (Agnew, 2000; Kock et al., 2007). The estimated catch in the 1996/97 season reached 33 000 tonnes, including 21 000 tonnes from the EEZ around the Prince Edward Islands and 12 000 tonnes off Crozet (CCAMLR 2018b, 2018c).[7] As many as 90 vessels were involved. Falling catch rates led to a reduction in the fleet, most of the remaining vessels being re-flagged to states that are not CCAMLR Contracting Parties. Increased enforcement activity within national zones is thought to have further reduced the total catch after 2002, though it also drove IUU activity into the high seas, particularly on the Kerguellen–Gaussberg Ridge, where maritime patrol is problematic and IUU catches are harder to estimate (Agnew, 2000, 2008).

CCAMLR responded with the measures summarized above, particularly attacking the markets for illegal catches through the Catch Documentation Scheme (CM 10-05). Coupled with the less-attractive catch rates that followed the depletion of the years of intense fishing, this approach has brought illegal fishing under control in the sub-Antarctic EEZs. IUU activity has continued in the high seas. Evidence of activity has been seen in Statistical Subarea 48.6 and there is known to be IUU fishing in Divisions 58.4.1 and 58.4.2, as well as Statistical Subareas 58.6 and 58.5.1, though only on high seas seamounts and perhaps around the edges of the Kerguelen Plateau, outside the French EEZ. Possible IUU activity in Division 58.4.3 remains a concern.

CCAMLR formerly estimated the magnitude of IUU catches but the estimation procedure was subsequently deemed unreliable, particularly once the majority of IUU fishing started to use bottom set gillnets, and has not been used since 2011. However, recent analysis of IUU gillnet vessel logbooks has suggested that catch rates are very similar to longlines (CCAMLR, 2018d, para 7.6).

The CCAMLR list currently includes 16 IUU vessels; 9 vessels have been sighted in the region since 2010, though this is part of a declining trend (number of sightings in 2014 – 10; 2015 – 6; 2016 – 3; 2017 – 1). In 2018 CCAMLR reported that there were no reports of IUU vessel sightings in the Convention Area in the 2017/18 season, though noted some occurred just before the season started (CCAMLR, 2018d, para 7.1), continuing the downward trend observed since a peak in 2006.

DESCRIPTION OF BOTTOM FISHERIES

The distinctions between the bottom fisheries in the high seas and those close to the islands and Antarctica are less clear than in other areas, especially south of 60° S. For these reasons, bottom fisheries adjacent to the various islands with surrounding EEZs have also been included in the description. This is not the case for the other regions presented in this review.

Early history and the first international conventions

Historically, the Southern Ocean has been home to some of the world's most productive and controversial fisheries. These have shaped much of the current ideologies in managing fisheries, and are mentioned here for that reason. Exploitation of the living resources of the Southern Ocean began with sealers on South Georgia harvesting fur seals as early as 1791. The taking of seals on their breeding beaches led to swift declines in abundance and the populations were essentially eliminated by 1830. Elephant seals,

[7] Earlier estimates of the 1996/97 IUU toothfish catch taken in the Indian Ocean sector of the CCAMLR convention area ran as high as 43 000 tonnes (Agnew, 2000).

right whales and even some penguins were hunted thereafter, leading to a sequence of severe depletions. "Modern" whaling reached South Georgia in 1904, and intensified in the 1920s when more efficient factory ships were developed. However, even by that time the large humpbacked whales were already depleted. The depletion of other whale species followed as the fishery switched target species, until around 1990 when the fishery effectively ended (Busch, 1985; Kock, 2000; Hewitt *et al*., 2008). Conventions and regulations controlling whaling entered into force in the 1930s and 1940s (Anon, 1931, 1937, 1946). However, it was not until the International Whaling Commission entered into force in 1946 that any form of real management was applied. The first scientific models and assessments were developed for whales and predictions made. Even so, and this being the first attempt at implementing such international agreements to harvested populations, successful control largely failed to protect the whales (Gulland, 1974). This, sadly, was followed by a similar pattern of over-exploitation on various demersal rockcod fish stocks around 1970 and these have not fully recovered.

Bottom-trawl fisheries for rockcod and icefish

Finfish fishing around South Georgia began by 1800, taking marbled rockcod as fresh provisions for the sealing crews. Similar subsistence activity continued there until the end of shore whaling in 1965. Through the twentieth century, a number of attempts were made to develop commercial fishery bases on the island but none prospered. However, the expanding global operations of the factory-freezer stern-trawler fleets reached Kerguelen in 1958, in the form of an exploratory trawler from the former USSR. Beginning in 1962, Japanese vessels surveyed the grounds around South Georgia, where they were followed by research and exploration vessels from several states. This work was extended to the South Orkneys in 1965. Commercial harvesting began around South Georgia during the 1969/70 season. The grounds fished were mostly close to shore and reported catch from the first season comprised nearly 400 000 tonnes of marbled rockcod. However, the following year saw little more than 100 000 tonnes of that species, plus 11 000 tonnes of the short-lived mackerel icefish. The South Georgia grounds were then all but abandoned for a few years (Kock, 1992), as the trawler fleets moved on to the hake of the Benguela Current ecosystem, off the African coast. The marbled rockcod around South Georgia have never recovered from that 1969/70 fishery. Indeed, by the mid-1980s that once-abundant species was depleted throughout the Southern Ocean (Constable *et al*., 2000). It has yet to rebuild sufficiently to support a directed fishery anywhere in the region.

Meanwhile, the former USSR's Black Sea fleet opened fisheries around Kerguelen (fishing at depths ranging from less than 200 m to almost 500 m) during the 1970/71 season. Catches that first year approached 100 000 tonnes, primarily of marbled rockcod, while the 1971/72 season yielded well over 200 000 tonnes, about half of which was marbled rockcod, with the remainder an equal mix of mackerel icefish and grey rockcod. Thereafter, catches dropped to much lower levels, aside from some years when mackerel icefish saw good recruitment. The fishing sometimes extended as far as Heard Island – though most, and perhaps all, remained within the limits of the modern EEZs. The Kerguelen fishery saw some limited participation by French trawlers from 1981 onwards but was otherwise in the hands of the former USSR, which operated under bilateral agreements after France declared its EEZ in 1978 (Kock, 1992).

Fishing effort around South Georgia increased again from the 1975/76 season, though annual catches rarely went above 100 000 tonnes, much of which was mackerel icefish. Other species taken were Patagonian rockcod, humped rockcod and marbled rockcod. Meanwhile, exploration had shown that the waters around the Crozets, Bouvet Island, the South Sandwich group and off the western coasts of the Antarctic Peninsula were unproductive for the range of species then exploited. However, during the 1977/78 season commercial trawling began off the South Orkneys and on Ob and

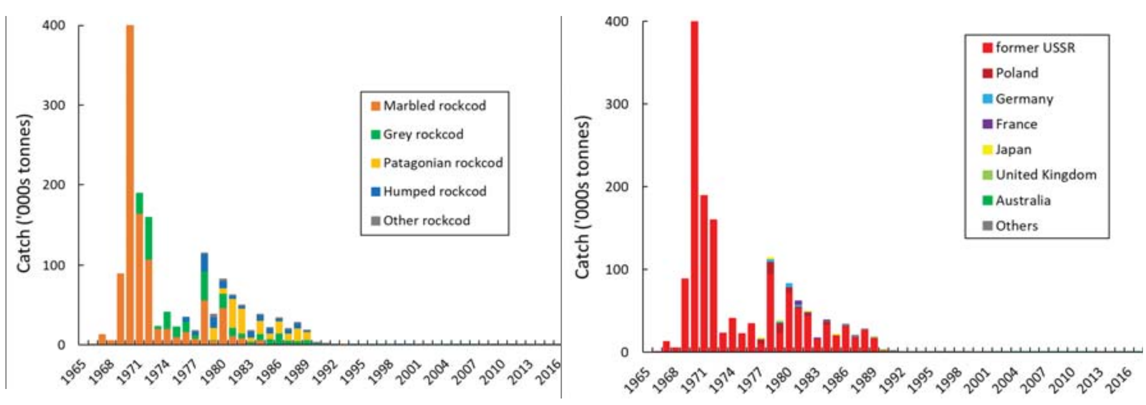
Lena seamounts (at 230–270 m depth), in the Indian Ocean sector. The following year, it expanded to the South Shetlands and the waters off the tip of the Peninsula (where the ground fished was 180–350 m deep). Those latter areas are all in the high seas – the seamounts lie 650 km from the nearest land, while the islands are south of 60° S. In their first season, the South Orkney grounds yielded 139 000 tonnes of reported catch, almost all mackerel icefish (much of it taken by midwater trawl – the first extensive use of such gear in the region), which had two strong year-classes in its population at the time. The highest catch rates were at depths of 200–300 m. Subsequent catches were very much lower and largely composed of humped rockcod. The South Shetlands and the Peninsula yielded less than 90 000 tonnes, almost all of which was in the first two years of fishing, half being from the same strong year-classes of mackerel icefish that were taken around the South Orkneys, while most of the rest was marbled rockcod and spiny icefish. The fishing was technically demanding, with small patches of good bottom on steep slopes, plus the challenges of ice drifting from the Weddell Sea, even in summer. The fishery on the Ob and Lena seamounts was intermittent, taking between nothing to a few thousand tonnes per year, except for 1986/87, when 11 500 tonnes were caught. Almost all was grey rockcod (Kock, 1992; Clark *et al*., 2007).

The continental shelves and slopes of Antarctica, aside from those of the Peninsula, were explored for fishing opportunities with little success before the 1990s. Starting from the 1982/83 season, between a few hundred tonnes and a maximum of under 2 000 tonnes were taken annually from the Indian Ocean sector, in fisheries that barely progressed beyond the initial exploration stage. Wilson's icefish and Patagonian rockcod were dominant in the catch (Kock, 1992).

In each area, the catch of most target species peaked in either the first season of commercial fishing or just a year or two later. The biomasses of most of the target resources of the early fisheries were believed to have been reduced to less than 20 percent of their virgin levels, many to less than 10 percent (Ainley and Blight, 2008).

The total catches of rockcod in the high seas and national zones of the Southern Ocean show the sequence of exploitation of marbled rockcod, then grey rockcod and finally Patagonian rockcod and other rockcod species. The main fishery exploited almost exclusively by vessels from the former USSR lasted from 1967 to 1990, with catches rarely exceeding 20 tonnes per year, until an increase after 2010 due to interest from the United Kingdom and Australia, presumably within their national waters (Figure 14.11; FAO, 2019).

FIGURE 14.11
Catches of rockcod in the Southern Ocean for 1965–2015 by (a) species and (b) flag state



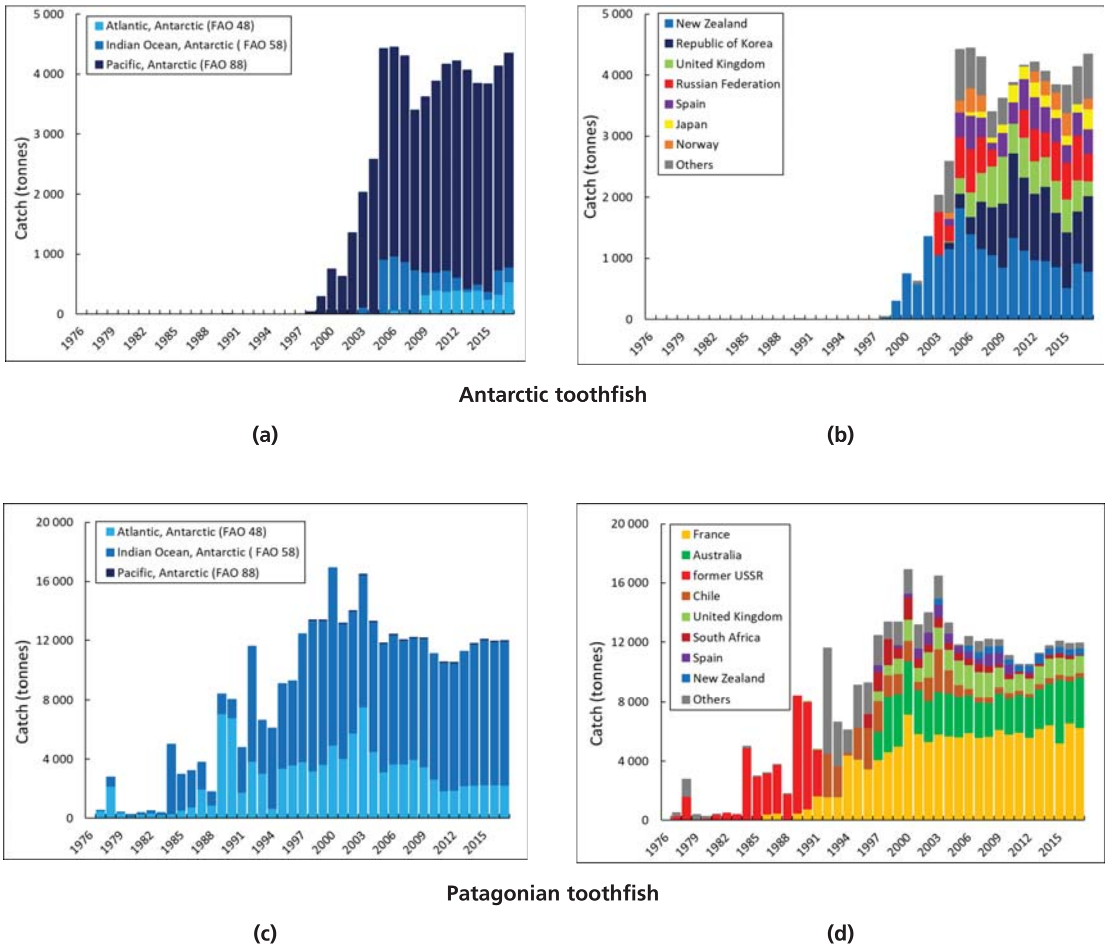
(a) **(b)**

Source: FAO, 2019.

Trawl and longline fisheries for toothfish

Catches of Antarctic and Patagonian toothfish by flag state and area are shown in Figure 14.12. Patagonian toothfish are caught throughout the year, whereas Antarctic toothfish are caught only during December–April owing to ice cover (Figure 14.13). Detailed descriptions are provided below.

FIGURE 14.12
Catches from the Southern Ocean of Antarctic toothfish by (a) area and (b) flag state and of Patagonian toothfish by (c) area and (d) flag state



Source: FAO, 2019.

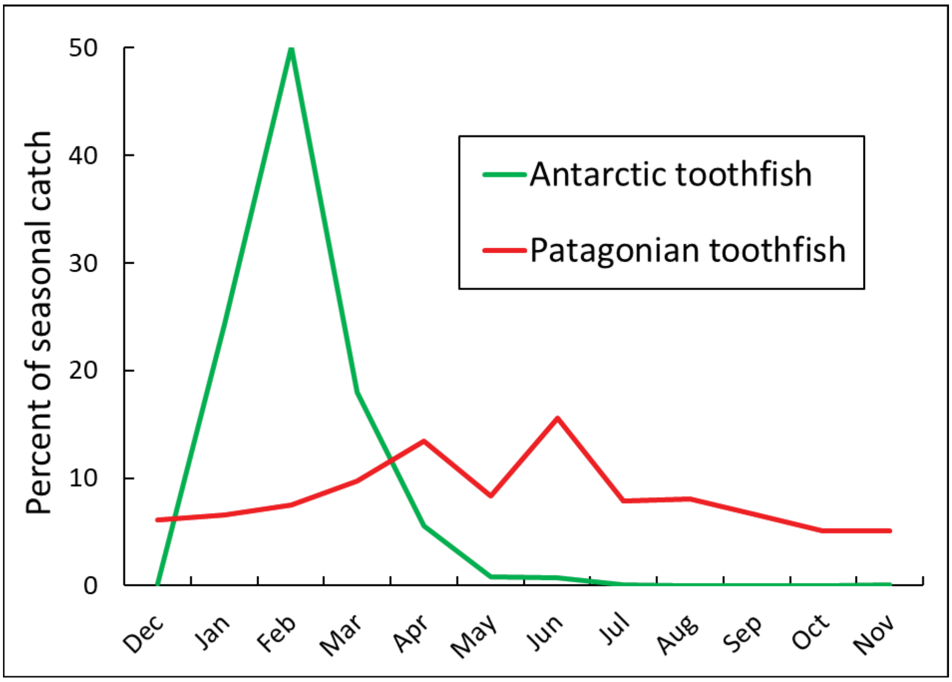
1976–2000

Bycatches of toothfish had been reported from the Southern Ocean since the 1976/77 season and (relatively) shallow-dwelling juveniles had probably been taken from the commencement of trawling in the 1960s. Trawlers from the former USSR targeted Patagonian toothfish on the grounds around Kerguelen from the 1984/85 season, initially at depths of 400–600 m and so probably taking mostly younger fish. A specialized, deep longline fishery for adult Patagonian toothfish emerged in Chilean waters in the mid-1980s.

Longlining was attempted around South Georgia the following year, leading to a commercial fishery from the 1988/89 season. The fishing method spread to the Kerguelen grounds from the 1990/91 season and catches from the Indian Ocean sector (Statistical Area 58) have predominated over Atlantic (Statistical Area 48)

FIGURE 14.13

High seas monthly catches of Patagonian and Antarctic toothfish throughout a fishing season (1 December to 30 November) for 2000–2017 combined

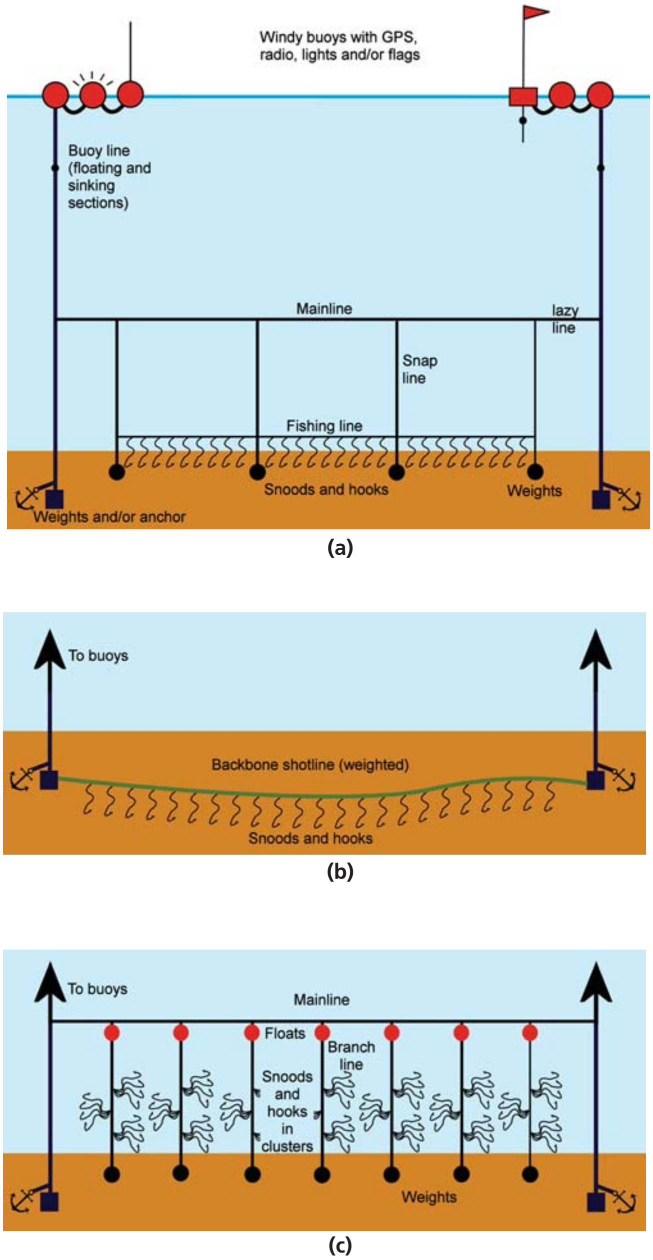


Source: CCLAMR, 2019.

catches ever since. Throughout the early and mid-1990s, longlining reached the Prince Edward, Crozet and Heard groups – which proved productive for toothfish, in contrast to their record with shallower-dwelling resources. Most areas were fished by longline (at depths sometimes as great as 2 000 m), though bottom trawling predominated in the Australian zone around Heard Island. Indeed, bottom trawling was the only permitted gear targeting toothfish in areas 58.4.1 and 58.4.3 (BANZARE Bank and Elan Bank) until 2000, and area 58.4.2 until 2002, before abruptly switching to only allowing longlines.

Three major variants have been used: Spanish longline, autoline and trotline (Figure 14.14), each with either circle or "J" hooks, baited with squid or jack mackerel, and deployed for 24–48 hour soaks. The "Spanish" gear has separate mainlines and fishing lines, the former connecting the anchors at either end, while the fishing line is attached to the mainline at intervals. The hooks are on monofilament snoods attached to the fishing line. Floats and 6–10 kg weights are rigged between each section of 25 hooks, to keep the latter off the seabed. There are typically 7 000 hooks per line and 2–3 lines are set per vessel per day. The hooks on the "Spanish" longlines must be hand-baited but the proprietary Autoline systems include auto-baiting, allowing setting of 30 000 hooks per day. As it is used for toothfish, Autoline gear typically uses weighted mainlines, which sink quickly and then lie close to the seabed (Collins *et al.*, 2010). Seabird mortalities are reduced but bycatch of grenadiers and rajids increase, relative to those of Spanish longlines (Kock *et al.*, 2007). Trotlines were developed by Chilean artisanal fishermen and were adopted in the Southern Ocean fishery to deter catch-depredation by mammals, particularly killer whales and sperm whales, which was causing significant wastage of potentially sustainable yields, besides negatively affecting the economics of the fishery. Various designs have been developed. All have

FIGURE 14.14
Diagrammatic representation of toothfish longline gears: (a) Spanish longline, (b) autoline system, and (c) trotline



Source: drawn from information provided in the CCAMLR fishing gear library, https://www.ccamlr.org/en/publications/fishing-gear-library.

branch lines at 40 m intervals, linking a mainline to weights; each branch line bears a clump of 8–20 hooks and usually some sort of sleeve that drops down over the catch as the gear is hauled (Collins *et al*., 2010). Trotlines have proven to reduce fish bycatch but they alter catch rates and reduce survival of "tagged and released" fish, which is a concern for CCAMLR stock assessments.

From the 1996/97 season, the fishery expanded into targeting Antarctic toothfish (Kock, 2000). This species is not as productive as its Patagonian congener and annual catches are only about 4 000 tonnes – as they have been since the 2005/06 season. It is mostly harvested south of 60° S and hence predominantly in the high seas. The most significant proportion has been harvested in the Ross Sea area of the Pacific sector (Area 88).

There was extensive IUU fishing of toothfish during the 1990s, particularly around the sub-Antarctic islands in the Indian Ocean sector, especially around the Prince Edward and Crozet groups. The estimated 33 000 tonnes taken in the 1996/97 season was more than three times the reported catch that year. Indeed, that single year's IUU catch from the waters around the Prince Edwards exceeded the total taken during the entire history of the regulated fishery (CCAMLR, 2018b, 2018c).

2000–2017

The only commercial bottom-contact fisheries operating in the high seas of the Southern Ocean in the 21st century have been those for Patagonian and Antarctic toothfish, with bycatches of grenadiers and rajids. Aside from some attempts at potting and the possibility to use trawls in the established fishery in area 58.5.2, longlines are now the only permitted fishing gear. The toothfish fisheries are divided into established, exploratory and research for the management purposes. This is not necessarily related to the amount of fish caught, but to the knowledge of the stock. The high seas fisheries are mostly exploratory and have stricter access controls, with the permitted fishing nations and the number of vessels they are allowed to employ outlined in the conservation measures.

Since 2009 the exploratory toothfish fisheries have operated from the regulated minimum depth of 550 m down to 2 200 m; however, larger Antarctic toothfish are typically taken between 1 000–1 600 m (Hanchet *et al.*, 2015). Some shallower longlining occurs in national zones and in established fisheries where the shallow depth restriction does not apply (CM 22-08 (2009)).

Established national fisheries

The established fisheries for Patagonian toothfish are limited to ones in CCAMLR Statistical Subareas 48.3B and 48.3C, around South Georgia, and in the EEZs around the Prince Edward, Crozet, Kerguelen and Heard groups, each of the latter four being confined to waters under national jurisdiction. Each was therefore subject to the intersection of CCAMLR and national management outlined above, while none of them were among the high seas fisheries of direct concern to this review. Graphs showing catches and catch limits for the various areas are given in Figure 14.15.

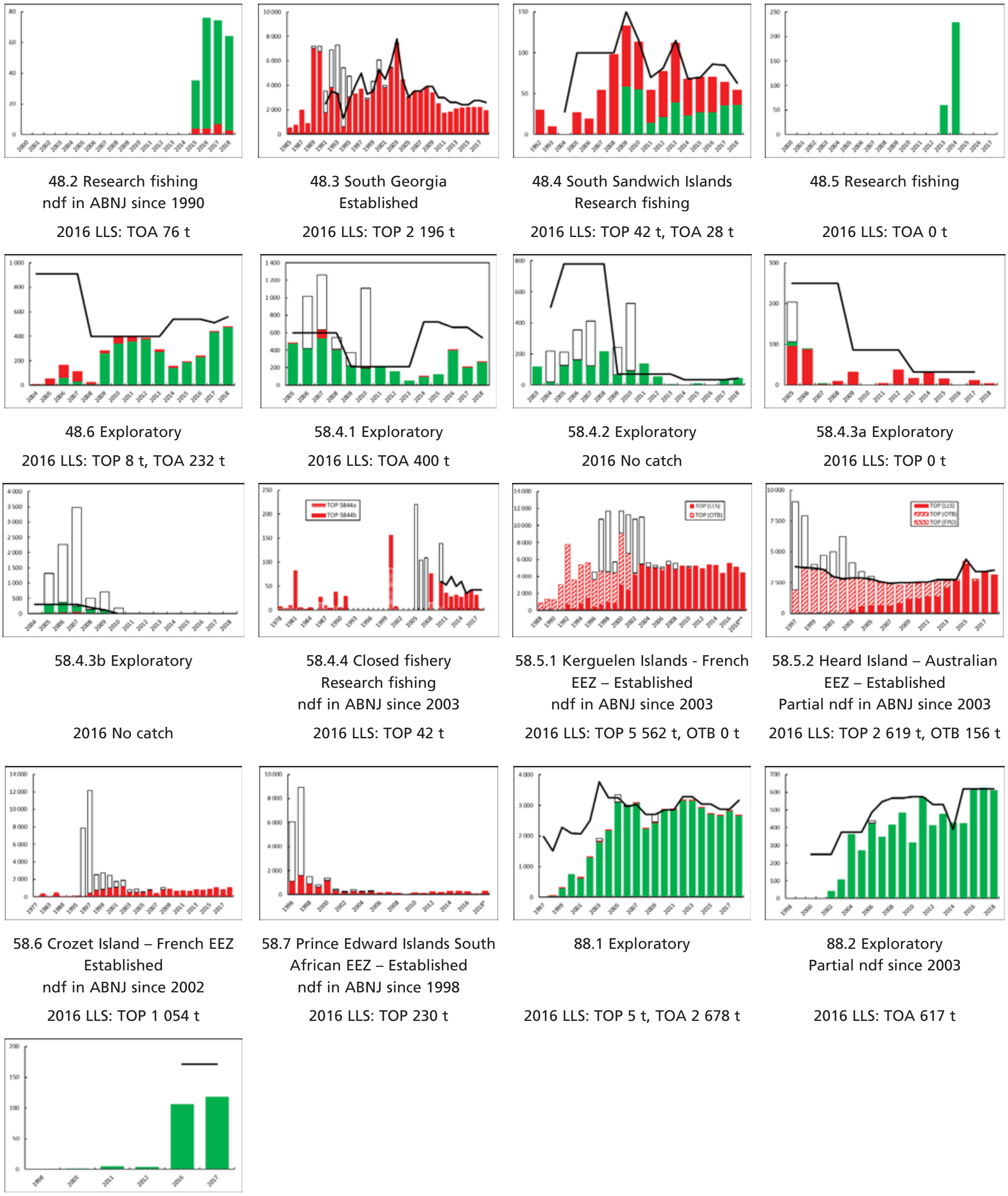
In brief:

- Only Patagonian toothfish are caught off South Georgia (Subarea 48.3), where catch limits have been applied since 1991,[8] with reported annual catches generally falling a little short of the limit. Some 7 500 tonnes were taken in 2003 but amounts declined thereafter and have been around 2 000 tonnes since 2011. During 2016 the reported catch of Patagonian toothfish was 2 196 tonnes. IUU fishing has been substantial in the past, reaching nearly 5 000 tonnes in 1994, but there is no evidence of IUU fishing after 2006 (CCAMLR, 2018f).
- The fishery around the Prince Edward Islands (Subareas 58.7 and part of Area 51 (Western Indian Ocean)), which catches only Patagonian toothfish, was initiated by South Africa in 1996, largely in response to the severe IUU fishing of that period. IUU catches reached 7 327 tonnes in 1997, but have declined swiftly and appear to have largely ended in 2005. While there is some evidence of ongoing IUU activity, its extent cannot be estimated. The fishery formerly used Autoline and Spanish longline systems, with some experimental pot fishing, but trotlines were introduced during 2008–2011, in response to depredation by killer whales. The catches in the registered fishery exceeded 1 000 tonnes in only three years, and

[8] Following CCAMLR, the last year of season is used as shorthand, so here 1991 refers to 1 Dec 1990–30 Nov 1991 (the 1990/91 season), etc.

FIGURE 14.15

Catches (tonnes, y-axis) of Patagonian toothfish and Antarctic toothfish throughout the divisions of the CCAMLR convention area, including areas under national jurisdictions, the reported IUU catches, and the CCAMLR adopted catch limits



48.2 Research fishing
ndf in ABNJ since 1990
2016 LLS: TOA 76 t

48.3 South Georgia
Established
2016 LLS: TOP 2 196 t

48.4 South Sandwich Islands
Research fishing
2016 LLS: TOP 42 t, TOA 28 t

48.5 Research fishing
2016 LLS: TOA 0 t

48.6 Exploratory
2016 LLS: TOP 8 t, TOA 232 t

58.4.1 Exploratory
2016 LLS: TOA 400 t

58.4.2 Exploratory
2016 No catch

58.4.3a Exploratory
2016 LLS: TOP 0 t

58.4.3b Exploratory
2016 No catch

58.4.4 Closed fishery
Research fishing
ndf in ABNJ since 2003
2016 LLS: TOP 42 t

58.5.1 Kerguelen Islands - French EEZ – Established
ndf in ABNJ since 2003
2016 LLS: TOP 5 562 t, OTB 0 t

58.5.2 Heard Island – Australian EEZ – Established
Partial ndf in ABNJ since 2003
2016 LLS: TOP 2 619 t, OTB 156 t

58.6 Crozet Island – French EEZ
Established
ndf in ABNJ since 2002
2016 LLS: TOP 1 054 t

58.7 Prince Edward Islands South African EEZ – Established
ndf in ABNJ since 1998
2016 LLS: TOP 230 t

88.1 Exploratory
2016 LLS: TOP 5 t, TOA 2 678 t

88.2 Exploratory
Partial ndf since 2003
2016 LLS: TOA 617 t

88.3 ndf since 2003
Research fishing
2016 LLS: TOP 106 t

TOA = Antarctic toothfish (green bars); TOP = Patagonian toothfish (red bars); IUU = open bars; LLS = Bottom-set longline (solid colour); OTB = Otter bottom trawl (upward diagonal lines); FPO = Pots (downward diagonal lines). TAC = solid black line. Catch is given for 2016 (being the 2015/2016 season).

Source: CCAMLR, 2018b, c, f–s

have amounted to 67–310 tonnes annually since 2010, with a catch of 230 tonnes of Patagonian toothfish reported for 2016 (CCAMLR, 2018b).

- The fishery around the Crozets (Subarea 58.6) is confined to waters deeper than 500 m. Its annual catches have been fairly stable since 2003 at 419–1 054 tonnes per annum, though it has been estimated that removals from the resource were 20 percent higher owing to fish lost to killer and sperm whales. The catch in 2016 was 1 054 tonnes of Patagonian toothfish. IUU fishing appears to have been eliminated from the EEZ (CCAMLR, 2018c).
- The Kerguelen fishery (Division 58.5.1) catches only Patagonian toothfish and began with bottom trawling; that did not finally end until 2010. Longlining commenced in 1992 and is now the sole fishing method. As around the Crozets, it is limited to depths greater than 500 m. Reported annual catches since 2010 have averaged a little over 5 000 tonnes, with the highest observed in 2016 at 5 562 tonnes of Patagonian toothfish. IUU fishing has been almost eliminated from the EEZ since 2010 (CCAMLR, 2018g).
- The Heard Island fishery (in Division 58.5.2) for Patagonian toothfish began with bottom trawling in 1997 and continues to date, though longlining was introduced in 2003 and has become increasingly important – longline catches have increased as trawl catches have declined. Pots were used and caught Patagonian toothfish in 2006–2013 with an average annual catch of 23 tonnes and a maximum catch in 2006 of 68 tonnes. Total reported annual catches have amounted to 2 458–4 226 tonnes since 2010. In 2016, 2 775 tonnes of Patagonian toothfish were reported, of which only 156 tonnes were taken by bottom trawl. There were also some minor catches using pots during 2006–2013, amounting to a maximum of 68 tonnes in 2006. There has been no evidence of IUU activity since 2007 (CCAMLR, 2018h).

Exploratory high seas fisheries

The remainder of the Southern Ocean toothfish fisheries occur in the high seas.

- Subarea 88.1 around the waters of the Ross Sea northward to 60° S has the largest fishery for Antarctic toothfish, with only very minor catches of Patagonian toothfish. The fishery commenced in 1998 and catches rose to 3 098 tonnes in 2005 and have remained more-or-less at that level – 2 259–3 178 tonnes – with all but a few tonnes being Antarctic toothfish. Early in the new century, grenadier bycatches sometimes exceeded 10 percent of the target catch, while small amounts of rajids were also taken. Bycatches have since been substantially reduced. In 2016, the reported directed catch was typical at 2 678 tonnes of Patagonian toothfish and only 5 tonnes of Antarctic toothfish, taken by 13 vessels under six different flags. The grounds vary from year to year, depending on ice conditions and allowable catches. The most consistently fished are on the continental slope of the Ross Sea south of 70° S, though some fishing takes place further north on seamounts where the Pacific/Antarctic Ridge is intersected by the Macquarie Ridge. When ice permits, some fishing occurs deeper within the Ross Sea in the most southerly fishable waters on the planet. Catch limits were first set in 1997, initially at much higher values than the actual catch. Since 2005 catches have been close to the allowable limits. No evidence of IUU fishing has been recorded since 2008, and it has always been below 10 percent of the regulated catch (CCAMLR, 2018i). A very significant development in this fishery was the agreement of the Ross Sea Region Marine Protected Area in 2016 (in force from December 2017). Much of the shelf slope area that had previously been the major fishing ground was closed, and some areas further north outside the MPA were opened. A Special Research Zone (SRZ) was retained within the MPA to allow for research to understand the impacts of fishing outside the MPA and the impacts of protection inside it. Furthermore, the area defined for the fishery was extended eastwards to 150° W, to coincide with the western edge of the MPA. The fishery is now managed with three catch limits, one for the seamounts north of 70° S, one for the area 70° S outside the MPA, and one for the SRZ.

- Subarea 88.2 has a much smaller fishery that operates within small selected areas known as Small Scale Research Units (SSRUs) that have specified TACs, some of which can be set at zero. Five SSRUs were open to fishing in the 2016 season east of the Ross Sea and close to the continent. Nine vessels from six flag states fished with a reported directed catch of only 617 tonnes that season, all of it Antarctic toothfish. The only recorded IUU fishing was in 2006 when 15 tonnes of Antarctic toothfish was identified (CCAMLR, 2018j).
- Subarea 48.6 is the most westerly of the high seas exploratory fisheries and includes all waters within the region between the 20° W and 30° E meridians. There, the 2016 season fishery was limited to just two longliners working within five designated "research blocks". Reported catches have approached 400 tonnes in some years but only amounted to 240 tonnes in 2016, almost all of it Antarctic toothfish, with just 8 tonnes of Patagonian toothfish. IUU activity was not recorded for 2006–2012, but has been since; however, its magnitude cannot be estimated (CCAMLR, 2018k).
- Southward of Heard Island, a few tens of tonnes of Patagonian toothfish are taken in an exploratory longline fishery from Elan Bank (CCAMLR Division 58.4.3a) in most years. There was no recorded fishing in the 2016 season. There has been no recorded IUU activity since 2005 but the potential for such fishing remains a concern for CCAMLR (CCAMLR, 2018l). Early this century, a few hundred tonnes per year were taken in a registered fishery from the nearby BANZARE Bank (CCAMLR Division 58.4.3b), most of it being Antarctic toothfish. IUU catches were much higher and are thought to have exceeded 3 200 tonnes in the 2007 season, before dropping to lower levels. There has been no registered fishery on the BANZARE Bank since 2012. The extent of any ongoing IUU fishing is unknown (CCAMLR, 2018m).
- In the 2016 season, exploration in CCAMLR Divisions 58.4.1 and 58.4.2 (adjacent to the continent and in the Indian Ocean sector) was limited to eight small areas, in which three flag states – each with a single longliner – took a total of 400 tonnes of Antarctic toothfish from Division 58.4.1, and no fishing in Division 58.4.2. Catches of Patagonian toothfish amount to 0–2 tonnes from each division. Average annual catches of Antarctic toothfish since the 2010 season have amounted to 190 tonnes and 35 tonnes for Divisions 58.4.1 and 58.4.2, respectively. In past years, IUU fishing in each division has sometimes exceeded the catch in the registered fishery. It continues in both. No estimates of its current magnitude are available, but its catches are thought to far exceed the allowable limit in Division 58.4.2 (CCAMLR, 2018n, 2018o).

Research fisheries

The one research fishery is also in waters subject to national jurisdiction:

- The South Sandwich Islands research fishery (Subarea 48.4) has seen longlining since 2005, with reported catches as high as 133 tonnes in 2009: Patagonian toothfish accounted for just over half; the rest was Antarctic toothfish. The former was primarily taken off the northern islands of the group, the latter towards the south. The 2016 season catch was 42 tonnes of Patagonian toothfish and 28 tonnes of Antarctic toothfish. TACs from 2005 were set at around 100 tonnes until 2013, but have now been reduced by some 30 tonnes, though the TACs are generally not reached. All catches are made at depths greater than 550 m and there have been no indications of IUU activity (CCAMLR, 2018p).

The other research fisheries are in the high seas:

- A small longline research fishery by Ukraine was approved for a single vessel in Subarea 48.2 south of South Georgia and began in 2015. Catches are primarily Antarctic toothfish supplemented by just a few tonnes of Patagonian toothfish with, respectively, 72 tonnes and 4 tonnes caught in 2016.A United Kingdom multi-year research programme was approved in 2016, but the first catches were in 2018. Since 2016 the catch limits have been 75 tonnes for the Ukraine research fishery in 48.2 and 41 tonnes for the United Kingdom programme. Some IUU fishing has been reported for 2016 (CCAMLR, 2018q).
- There was also a small research fishery in Subarea 48.5 in the 2013 and 2014 seasons taking 60 and 229 tonnes of Antarctic toothfish respectively. There was no fishery in the 2016 season (CCAMLR, 2018r).
- Since 2016 Subarea 88.3 has also had a small research fishery that has been conducted by single longline vessels with catch limits being 171 tonnes for the 2016 and 2017 seasons. Catches have been almost exclusively Antarctic toothfish, with 106 tonnes taken in 2016 and no records of IUU fishing (CCAMLR, 2018r).

Closed fishery

- Stocks of toothfish in Division 58.4.4 were believed to be at a low level and the directed fishery for toothfish was closed in 2002 (CM 32-02). However, significant levels of IUU fishing continued, especially in 2005–2007 and 2010, where it exceeded caches in previous years for the registered fishery. In 2008 and from 2010 onwards, a catch limit was set for research fishing that has declined from 80 tonnes in 2008 down to 42 tonnes in 2018. A total of 42 tonnes of Patagonian toothfish were caught in the 2015/16 season (CCAMLR, 2018s).

In summary, the total reported directed catch from the Antarctic high seas during 2016 (the 2015/16 season) amounted to an estimated 4 408 tonnes, almost all of it Antarctic toothfish, though there was some Patagonian toothfish. Bycatches included 124 tonnes of mixed macrourid grenadiers, plus small amounts of other species. A considerable proportion of that catch was taken within 200 nautical miles of land and hence in waters that would not be high seas were it not for the provisions of the *Antarctic Treaty*. As Bensch *et al.* (2009) noted for the 2006/07 season – and the same trend continues – the total toothfish catch from the Southern Ocean was about four times higher than the high seas catch, an increase mainly resulting from the Patagonian toothfish caught in the EEZs around the sub-Antarctic islands. IUU fishing caught additional toothfish in the region but likely a considerably smaller quantity than was reported by the legal fisheries.

Trap fisheries for crab

There have been attempts to develop other fixed-gear fisheries in the region. Notably, a pot fishery for lithodid crabs (*Paralomis spinosissima* and *P. formosa*) was attempted around South Georgia from the 1992/93 season but only lasted three years (Kock, 2000).

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15. Arctic Ocean

FAO Major Fishing Area 18 and a portion of Area 27

SUMMARY

The Arctic Ocean is the most northerly ocean with seasonally variable ice cover. The central part lies beyond 200 nautical miles from any land and is therefore high seas and known as the central Arctic Ocean. There is currently no fishing in the area as a result of extended ice cover, but climate change may alter this – recent summer ice minimums are among the lowest on record. An agreement was reached among potential fishing nations to prohibit fishing, in the event of reduced ice cover, until regional or subregional fisheries management organisations are in force to manage those fisheries which may emerge. The high seas of the central Arctic Ocean north of the Atlantic currently falls within the NEAFC regulatory area.

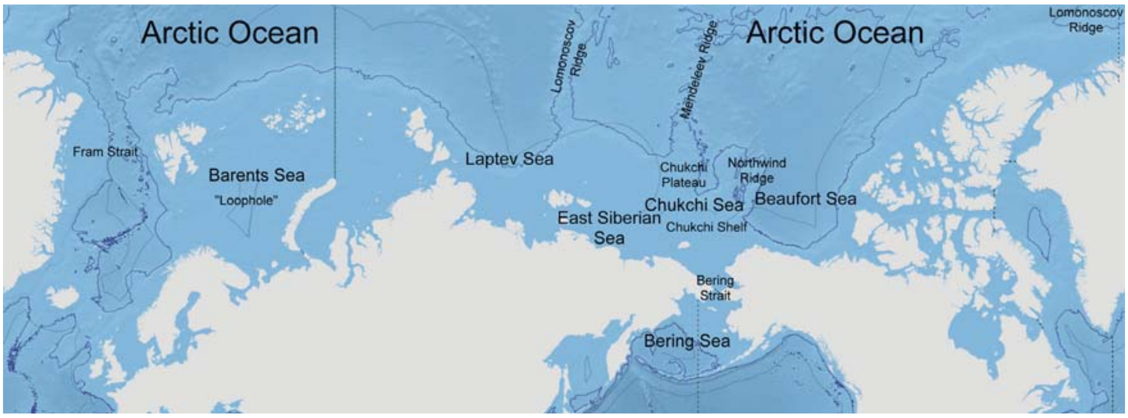
GEOGRAPHIC AND OCEANOGRAPHIC DESCRIPTION

The Arctic Ocean, including its marginal seas, lies north of the Pacific Ocean at the Bearing Strait; to the north of the Atlantic Oceans the boundary is somewhat irregular and generally includes Hudson Bay (Figure 15.1 and Figure 15.2). The continental shelves are narrow from Point Barrow, Alaska, to the east, through the Canadian Arctic Archipelago to northern Greenland. By contrast, moving westwards from Point Barrow to Svalbard, the shelves are wide (very wide, in places) and often very shallow. However, there are multiple island groups lying north of the Eurasian mainland: almost all of that extensive continental shelf thus falls under national jurisdiction. Other than the "Loophole", the Arctic high seas comprise only a single area, commonly referred to as the "central Arctic Ocean", which contains continental-shelf depths only to the north of easternmost Siberia and the northwest of Alaska, primarily in the Chukchi Sea. There, the shelf proper is extended by the Chukchi Plateau, with a depth of at least 250 m, and the adjacent Northwind Ridge. Only 121 000 km^2 of the central-Arctic high seas is shallower than 400 m, of which 61 000 km^2 shallower than 200 m (Table 15.1). Elsewhere, the high seas of the region comprise deep ocean basins, traversed by a number of ridges – particularly the Lomonosov Ridge, which lies across the Pole and rises to 400 m depth – and the Mendeleev Ridge, projecting north from the Siberian shelf. A smaller area in the northern part of the Arctic Ocean consists of only high seas, as it is more than 200 nautical miles from any land mass, and is known as the central Arctic Ocean (Figure 15.1).

TABLE 15.1
Area statistics for the Arctic Ocean

Geographical area	Surface area (km^2)
Total sea area	10 660 000
Area of high seas	2 806 000
Area of high seas shallower than 200 m	61 000
Area of high seas shallower than 400 m	121 000
Area of high seas shallower than 1 000 m	225 000
Area of high seas shallower than 2 000 m	628 000

FIGURE 15.1
Map of Arctic Ocean



200 nautical mile arcs, 2 000 m isobath (GEBCO), FAO fishing areas.

Source: FAO VME Database, Mercator projection.

FIGURE 15.2
Map of the central Arctic Ocean (CAO) showing international waters more than 200 nautical miles from any coast

Source: https://doi.org/10.1016/j.marpol.2015.10.015, country names and boundaries removed.

Arctic oceanography is complex, varying sharply over space, depth and time. There are three highly variable inputs: (1) freshwater from runoff and ice melt, all of which contributes to the surface layer; (2) relatively warm saline Atlantic water which flows both across the Barents Sea and along the continental slope through Fram Strait between Greenland and Svalbard; and (3) a smaller quantity of Pacific water which enters through the Bering Strait. The latter two contribute to subsurface layers, while winter cooling and brine release from sea ice combine to create very dense bottom water. Hence, in most parts of the Arctic Ocean there is an intense, temporally variable layering of water masses, in addition to very low temperatures (Carmack and Wassmann, 2006) – notably lower compared to other regions where fisheries have developed. The Chukchi Plateau, and the adjacent continental shelf and slope, are flooded with water between about +0.5–1.5 °C. The lowest summer temperatures are found in a layer of Pacific winter water at 100–150 m depth. The warmest, derived from the saline Atlantic water, occurs at 300–500 m depth; below that the deep water is approximately 0 °C (Nishino *et al*., 2011a) and viable commercial fishing is unlikely at such temperatures. However, early in the present century an anomalously inflow through Fram Strait raised the subsurface maximum in the vicinity of the Chukchi Plateau to above +0.7 °C (McLaughlin *et al*., 2011), which may be indicative of future climate change trends.

Change is more apparent in the summer extent of sea ice. The recent warming trend has reduced coverage to such a degree that, at its current minimum level (recorded in September 2012), 40 percent of the high seas area was open water (Shephard *et al*., 2016), including most of that lying in and to the north of the Beaufort, Chukchi and East Siberian seas (Figure 15.1). Ice thickness and age has also decreased, with ice older than four years almost gone by 2010 (McLaughlin *et al*., 2011). Some recovery may occur in the medium term, but current projections suggest that the entire Arctic Ocean will be ice-free in the summer by 2100 (Hollowed *et al*., 2013). The complexities are such that it is not yet possible to predict the ecological consequences of that loss of cover, nor even whether primary production will increase or decrease overall, though it is likely that different parts of the region will see opposite trends (Carmack and Wassmann, 2006; McLaughlin *et al*., 2011; Nishino *et al.*, 2011b; Hollowed *et al*., 2013). The central Arctic Ocean will, however, continue to be ice-covered in winter and it is the winter conditions which lead to the production of the dense, cold bottom water.

POTENTIAL FOR FUTURE DEEP SEA FISHERIES

There are currently no fisheries in the Arctic Ocean.

Across a very broad arc of longitudes from 155° W (near Point Barrow) eastwards, via the waters north of Greenland, to 130° E (which pass through the Laptev Sea), a combination of continuing year-round ice coverage, very cold temperatures and the limited extent of seabed at fishable depths in the high seas of the central Arctic Ocean makes the short- or medium-term development of bottom fisheries improbable. Only on the southern portions of the Lomonosov and Mendeleev Ridges, on the high seas portion of the East Siberian shelf and slope – and particularly on the Chukchi outer shelf, slope and Plateau – is development of high seas bottom fishing plausible in the foreseeable future. Even in the latter development must await either marked a strengthening of the Atlantic inflow, higher temperatures at upper-slope depths, or else the pronounced summer warming of the Chukchi Shelf shallows.

Hollowed *et al.* (2013) have recently considered which of the resource species currently exploited in the Barents and Bering Seas might, in future, become harvestable resources in the Arctic Ocean – though they did not distinguish between high seas and EEZ fisheries in the region. While no definitive conclusions are possible as yet, of the 17 species considered, including some pelagic species, only six were judged to have high potential, while another six were thought possible. Adding a restriction to the high seas – hence to the arc from Point Barrow westwards to the Lomonosov Ridge – while limiting consideration to only bottom-contact fishing, leaves the only prospects for future fisheries as polar cod, Bering flounder, Greenland halibut and snow crab (each of which is already present in the area of interest), or else yellowfin sole or Alaska plaice (currently present in the northern Bering Sea). There are also some elasmobranchs which might support brief pulse fisheries but are unlikely to sustain ongoing exploitation. Hollowed *et al.* (2013) noted Greenland shark and Arctic skate as possibilities, but the former has recently been claimed as the longest-lived fish known, with one individual supposedly aged about 400 years (Nielsen *et al.*, 2016). Such a long life implies an extremely low natural mortality rate and potentially-sustainable yields that would consist of a correspondingly low proportion of the unexploited biomass – if public perceptions of extreme longevity did not lead to a simple ban on directed fishing.

MANAGEMENT OF HIGH SEA BOTTOM FISHERIES

The segment of the central Arctic Ocean between the 51° E and 44° W meridians (approximately from Novaya Zemlya to Greenland), extending north to the Pole, falls within the NEAFC convention area. The high seas portion of that segment is, however, among the least likely to see fisheries development.

The limited prospects for development in the short term notwithstanding, discussions leading towards the multilateral management of fisheries in the high seas of the central Arctic Ocean have commenced. The United States of America raised the issue as early as 2007. Since 2010, the five coastal states (the "Arctic Five") have conducted a series of meetings, with the express intent of involving other parties in due course. In 2015, those discussions led to a Declaration Concerning the Prevention of Unregulated High Seas Fishing in the Central Arctic Ocean (the "Oslo Declaration"), which committed the Arctic Five, *inter alia*, to authorizing their own vessels to fish in the area only under future regional or subregional fisheries management organizations or arrangements, in addition to cooperating on monitoring, control and surveillance, and encouraging other states to introduce interim measures consistent with those adopted. A multilateral meeting in December 2015, which included distant-water fishing states as well as the Arctic Five, extended the process. Further meetings are scheduled to follow (Molenaar, 2015; Shephard *et al*., 2016).

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Appendix A. Species list

This review is concerned with fishery resource species and is addressed to a general audience. With a few exceptions, , common English names have been used throughout this review.

For greater clarity, common names are listed alongside the corresponding scientific name below – as well as their names in the other UN languages where these are known. Names have been sourced from the FAO ASFIS and FishBase lists. Synonyms and other alternative common names are shown in parentheses.

English	Scientific	3-alpha code	Arabic	Chinese	French	Russian	Spanish
Elasmobranch							
bluntnose sixgill shark	*Hexanchus griseus*	SBL		灰六鳃鲨	Requin griset		Cañabota gris
Greenland shark	*Somniosus microcephalus*	GSK		小头睡鲨 (大西洋睡鲨)	Laimargue du Groenland	Акула полярная атлантическая	Tollo de Groenlandia
kitefin shark	*Dalatias licha*	SCK		铠鲨	Squale liche	Далатия (=чёрная пряморотая акула)	Carocho
leafscale gulper shark	*Centrophorus squamosus*	GUQ		叶鳞鲨	Squale-chagrin de l'Atlantique		Quelvacho negro
Portuguese dogfish (1)	*Centroscymnus coelolepis*	CYO	كلب البحر برتغالي شائع	腔鳞荆鲨	Pailona commun	Акула португальская	Pailona
siki sharks	mainly leafscale gulper shark and Portuguese dogfish						
spurdog	*Squalus acanthias*	DGS	قِرش الإسكندر شُويكة	柯氏角鲨	Aiguillat commun	Катран (=акула колючая обыкновенная)	Mielga
thorny (= starry) skate	*Amblyraja* (=*Raja*) *radiata*	RJR	شِفنين بحري شعاعية	辐鳐	Raie radiée	Zvezdchatiy skat	Raya radiante
Finfish							
pelagic armourhead (=southern boarfish)	*Pentaceros* (=*Pseudopentaceros*) *richardsoni*	EDR		李氏拟五棘鲷	Tête casquée pélagique	Рыба-кабан	
Acadian redfish	*Sebastes fasciatus*	REN		條紋平鮋	Sébaste rose		Chancharro
Alaska plaice	*Pleuronectes quadrituberculatus*	ALP		帕氏鲽	Plie de l'Alaska	Zheltobryukhaya kambala	Solla de Alaska
alfonsino	*Beryx* spp.	ALF	عُنقُد طويل	大目金眼鲷	Béryx nca	Бериксы	Alfonsinos nep
amberjacks	*Seriola* spp.	AMX			Sérioles nca	Сериолы (=желтохвосты)	Medregales nep
American plaice (=long rough dab)	*Hippoglossoides platessoides*	PLA	هوشع كندي	拟庸鲽	Balai (=Plie canadienne)	Камбала-ерш	Platija americana
angler (=monk)	*Lophius piscatorius*	MON	عفريت البحر شائع	鮟鱇	Baudroie commune	Удильщик европейский (=морской черт)	Rape

English	Scientific	3-alpha code	Arabic	Chinese	French	Russian	Spanish
Antarctic toothfish	*Dissostichus mawsoni*	TOA			Légine antarctique	Клыкач антарктический	Austromerluza antártica
Argentine hake	*Merluccius hubbsi*	HKP		阿根廷無鬚鱈	Merlu d'Argentine	Мерлуза аргентинская	Merluza argentina
Atlantic cod	*Gadus morhua*	COD		大西洋鱈	Morue de l'Atlantique	Треска атлантическая	Bacalao del Atlántico
Atlantic halibut	*Hippoglossus hippoglossus*	HAL		大西洋庸鰈	Flétan de l'Atlantique	Палтус белокорый обыкновенный	Fletán del Atlántico
Atlantic herring	*Clupea harengus*	HER		大西洋鯡	Hareng de l'Atlantique	Сельдь атлантическая	Arenque del Atlántico
Atlantic mackerel	*Scomber scombrus*	MAC		鲭(大西洋鲭)	Maquereau commun	Скумбрия обыкновенная	Caballa del Atlántico
Baird's slickhead (=smooth head)	*Alepocephalus bairdii*	ALC		贝氏平头鱼	Alépocéphale de Baird	Плешан	Talismán celindra
bar rockcod/Convict grouper	*Epinephelus (=Hyporthodus) septemfasciatus*	EIF	لُوْز سَجين	七帶石斑鱼	Mérou bagnard		Mero carcelario
bar rockcod/Sevenbar grouper	*Hyporthodus (=Epinephelus) ergastularius*	YHP		灰帶石斑魚	Mérou sept raies		Mero de siete bandas
beaked redfish	*Sebastes mentella* and *S. fasciatus*						
Bering flounder	*Hippoglossoides robustus*			粗壯擬庸鰈	Plie de Bering	камбала северная	
black cardinalfish	*Epigonus telescopus*	EPI		少耙後竺鯛	Poisson cardinal	Эпигонус-телескоп	Boca negra(=Pez del diablo)
black oreo	*Allocyttus niger*	BOE		黑異海魴	Arrose noir	Аллоцит черный	
black scabbardfish	*Aphanopus carbo*	BSF		黑等鰭叉尾带鱼	Sabre noir	Рыба-сабля угольная	Sable negro
blackbellied angler	*Lophius budegassa*	ANK	عفريت البحر شيطان	犁齿鮟鱇	Baudroie rousse	Удильщик европейский (=морской черт)	Rape negro
blackbelly rosefish	*Helicolenus dactylopterus*	BRF		黑腹無鰾鮋	Sébaste chèvre		Gallineta
blackspot (=red) seabream	*Pagellus bogaraveo*	SBR	مرجان وردي	黑斑小鯛	Dorade rose	Пагель пятнистый	Besugo

English	Scientific	3-alpha code	Arabic	Chinese	French	Russian	Spanish
blue antimora	*Antimora rostrata*	ANT		藍擬深海鱈	Antimora bleu	Антимора (=хек голубой)	Mollera azul
blue eye trevalla (=bluenose warehou)	*Hyperoglyphe antarctica*	BWA	خزّان مَزرورق	南极栉鲳	Rouffe antarctique		Rufo antártico
blue ling	*Molva dypterygia*	BLI		藍魣鱈	Lingue bleue	Мольва голубая (=биркеланга)	Maruca azul
blue whiting	*Micromesistius poutassou*	WHB	غُبر أزرق	小鰭鱈	Merlan bleu	Путассу северная	Bacaladilla
bluenose warehou	*Hyperoglyphe antarctica*	BWA	خزّان مَزرورق	南极栉鲳	Rouffe antarctique		Rufo antártico
cape bonnetmouth	*Emmelichthys nitidus*	EMM		谐鱼	Andorrève du Cap	Красноглазка южная	Andorrero del Cabo
capelin	*Mallotus villosus*	CAP		毛鳞鱼	Capelan	Мойва	Capelán
cardinalfish	*Epigonus* spp.	CDL			Poissons-cardinaux nca	Эпигонусы	Peces cardenal nep
common mora	*Mora moro*	RIB	جُسْنَة شائعة	深海鱈	Moro commun	Мора	Mollera moranella
crimson jobfish	*Pristipomoides filamentosus*	PFM	سمك عامل أُرجُوان	丝鳍紫鱼	Colas fil		Panchito hebra
deep-sea redfish	*Sebastes mentella*	REB		尖吻平鲉	Sébaste du Nord	Клювач	Gallineta nórdica
deep-water Cape hake	*Merluccius paradoxus*	HKO		深水無鬚鱈	Merlu du large du Cap		Merluza de altura del Cabo
European conger	*Conger conger*	COE	قرنقو	欧洲康吉鳗	Congre d'Europe	Угорь морской (=конгер)	Congrio común
European hake	*Merluccius merluccius*	HKE		欧洲无须鳕	Merlu européen	Мерлуза восточноатлантическая	Merluza europea
gemfish	*Rexea solandri*	GEM		南短蛇鲭	Escolier tifiati	Рексия южная (=южная змеевидная макрель)	Escolar plateado
golden redfish	*Sebastes norvegicus (=S. marinus)*	REG		海平鲉	Sébaste doré	Окунь золотистый	Gallineta dorada
greater argentine	*Argentina silus*	ARU		大西洋水珍魚	Grande argentine		Pez plata
greater forkbeard	*Phycis blennoides*	GFB		鰯狀褐鳕	Phycis de fond	Налим нитеперый большеглазый	Brótola de fango

English	Scientific	3-alpha code	Arabic	Chinese	French	Russian	Spanish
Greenland halibut	*Reinhardtius hippoglossoides*	GHL		馬舌鰈	Flétan noir	Палтус черный (=палтус гренландский)	Fletán negro
grey rockcod	*Lepidonotothen (=Notothenia) squamifrons*	NOS		大鱗雅南極魚	Bocasse grise	Нототения серая (=сквама)	Trama gris
haddock	*Melanogrammus aeglefinus*	HAD		黑线鳕	Églefin	Пикша	Eglefino
hapuku	*Polyprion oxyheneios*	WHA		長體多鋸鱸	Cernier de Nouvelle-Zélande	Хапуку	Cherna hapuku
hoki, blue grenadier, Patagonian grenadier	*Macruronus novaezelandiae*	GRN		蓝尖尾无须鳕	Grenadier bleu	Макруронус новозеландский	Cola de rata azul
humped rockcod	*Gobionotothen (=Notothenia) gibberifrons*	NOG		隆头南极鱼	Bocasse bossue	Нототения зеленая	Trama jorobada
imperial blackfish	*Schedophilus ovalis*	HDV	سمك أسود امْبراطُوري	卵形高体鲳	Rouffe impérial		Rufo imperial
jack mackerel	*Trachurus* spp.	JAX		巴拢	Chinchards noirs nca	Ставриды	Jureles nep
Japanese armorhead	*Pentaceros japonicus*			五棘鯛			
Japanese butterfish	*Hyperoglyphe japonica*			日本栉鲳			
kingklip	*Genypterus capensis*	KCP		岬羽鼬鳚	Abadèche du Cap	Конгрио африканский	Congribadejo(=Rosada) del Cabo
lemon sole	*Microstomus kitt*	LEM		小头油鲽	Limande sole		Mendo limón
ling	*Molva molva*	LIN		魣鳕	Lingue franche	Мольва обыкновенная	Maruca
longtail red snapper	*Etelis coruscans*	ETC	عصموديّ شُعلة	丝尾红钻鱼	Vivaneau flamme		Pargo de llama
longtail southern cod	*Patagonotothen ramsayi*	PAT		拉氏南美南极鱼	Notothénia queue longue	Нототения патагонская Рамсея	Nototenia coluda
mackerel icefish	*Champsocephalus gunnari*	ANI		裘氏鱷頭冰魚	Poisson des glaces antarctique	Ледяная рыба (=белокровка Гуннара)	Draco rayado
marbled rockcod	*Notothenia rossii*	NOR		花紋南極魚	Bocasse marbrée	Нототения мраморная	Trama jaspeada
megrim	*Lepidorhombus boscii*	LDB		四斑鱗鮃	Cardine à quatre taches		Gallo de cuatro manchas
mirror dory	*Zenopsis nebulosa (=Z. nebulosus)*	ZNE		云纹亚海鲂			

English	Scientific	3-alpha code	Arabic	Chinese	French	Russian	Spanish
monkfish	*Lophius* spp., including *L. piscatorius* and *L. budegassa*	MNZ	عفريت البحر شائع	鮟鱇	Baudroies nca	удильщик	Rapes nep
morwong	*Nemadactylus* spp.	MOW		長鰭唇指		Джакас серый	
North Pacific (=slender, =pelagic) armourhead	*Pentaceros (=Pseudopentaceros) wheeleri*	EDJ		大洋拟五棘鲷	Tête casquée pélagique	Рыба-кабан	
ocean blue-eye trevalla (=violet warehou)	*Schedophilus velaini (=S. labyrinthicus)*	SEY		伐氏高体鲳	Rouffe africain		Rufo africano
oilfish	*Ruvettus pretiosus*	OIL		台氏棘鳞蛇鲭	Rouvet		Escolar clavo
orange roughy	*Hoplostethus atlanticus*	ORY		大西洋胸棘鯛	Hoplostète orange	Большеголов атлантический (=берикс исландский)	Reloj anaranjado
oreo, oreo dory	Oreosomatidae	ORD		菱体新海魴	Oréos nca	Ореосомовые (=бугристые солнечники)	Oreós nep
Pacific cod	*Gadus macrocephalus*	PCO		太平洋鱈	Morue du Pacifique	Треска тихоокеанская	Bacalao del Pacífico
Pacific halibut	*Hippoglossus stenolepis*	HAP		狭鱗庸鰈 (太平洋庸鰈)	Flétan du Pacifique	Палтус белокорый тихоокеанский	Fletán del Pacífico
Pacific ocean perch	*Sebastes alutus*	OPP		革平鮋	Sébaste du Pacifique	Клювач тихоокеанский	Gallineta del Pacífico
Patagonian rockcod	*Patagonotothen guntheri*	GHP		冈氏南美南极鱼			
Patagonian toothfish	*Dissostichus eleginoides*	TOP		小鱗犬牙南極魚	Légine australe	Клыкач патагонский	Austromerluza negra
pink cusk eel	*Genypterus blacodes*	CUS		小孔羽鼬鳚	Abadèche rosé	Конгрио черный	Congribadejo rosado
pink maomao	*Caprodon longimanus*	RNL		長鰭菱牙鮨			
polar cod	*Boreogadus saida*	POC		北鱈	Morue polaire	Сайка (=полярная тресочка)	Bacalao polar
red cod	*Salilota australis*	SAO		澳洲犁齒鱈	More têtard	Салилота	Bacalao criollo
redfinned emperor	*Lethrinus miniatus*	LHI		奄美裸頰鯛	Gueule rouge		
redfish	*Sebastes* spp. in North Atlantic	RED			Sébastes de l'Atlantique nca	Окуни морские	Gallinetas del Atlántico nep

English	Scientific	3-alpha code	Arabic	Chinese	French	Russian	Spanish
Risso's smooth-head	*Alepocephalus rostratus*	PHO		鼻平頭魚	Caussinie		Talisman
rockfish	*Sebastes* spp. and other Sebastinds in North Pacific						
rosefish	*Helicolenus* spp.	ROK	حمام البحر	斑无鳔鮋	Sébastes chèvres nca	Синеротий окунь	Rascacios sureños nep
rougheye rockfish	*Sebastes aleutianus*	SFT		阿留申平鮋		Ерш алеутский	
roughhead grenadier	*Macrourus berglax*	RHG	رمّانيّة قويّة الرأس	北大西洋长尾鳕	Grenadier berglax	Макрурус северный	Granadero berglax
roundnose grenadier	*Coryphaenoides rupestris*	RNG		圆吻突吻鳕 (岩突吻鳕)	Grenadier de roche	Макрурус тупорылый	Granadero de roca
rubyfish	*Plagiogeneion rubiginosum*	RYG		玫瑰斜諧魚		Красноглазка розовая (=рубинка)	
rudderfish	*Centrolophus niger*	CEO	سمك دقّة المرطب أسود	黑长鲳	Centrolophe noir	Центролоф черный (=черныш)	Romerillo
sablefish	*Anoplopoma fimbria*	SAB		裸盖鱼 (裸头鱼)	Morue charbonnière	Угольная рыба	Bacalao negro
saithe	*Pollachius virens*	POK	قدّيّة سوداء	青鳕	Lieu noir	Сайда	Carbonero(=Colín)
shallow-water Cape hake	*Merluccius capensis*	HKK		南非无须鳕	Merlu côtier du Cap	мерлуза капская	Merluza del Cabo
silver scabbardfish	*Lepidopus caudatus*	SFS	سبته	大西洋叉尾带鱼	Sabre argenté	Лепидоп	Pez cinto
skilfish	*Erilepis zonifer*	ESZ		白斑裸盖鱼		Эрилепис	
Sky emperor, dame berri	*Lethrinus mahsena*	LTQ		切胸裸頬鯛	Empereur mahsena		Emperador mahsena
smooth oreo	*Pseudocyttus maculatus*	SSO		奇海魴	Arrose lisse	Псевдоцит пятнистый	
southern blue whiting	*Micromesistius australis*	POS		南蓝鳕	Merlan bleu austral	Путассу южная	Polaca austral
southern hake	*Merluccius australis*	HKN		多鳞無鬚鳕	Merlu austral	Мерлуза новозеландская	Merluza austral
spikey oreo	*Neocyttus rhomboidalis*	ONV		菱体新海魴		Неоцит	
spiny Wilson's icefish	*Chaenodraco wilsoni*	WIC		威氏棘冰魚	Grande-gueule épineuse	Белокровка Вильсона	Draco espinudo

English	Scientific	3-alpha code	Arabic	Chinese	French	Russian	Spanish
tusk	*Brosme brosme*	USK	بروسمة	单鳍鳕	Brosme	Менек (=морской налим)	Brosmio
walleye (=Alaska) pollock	*Theragra chalcogramma*	ALK	قدّية ألاسكا	狭鳕	Lieu de l'Alaska	Минтай	Colín de Alaska
warty oreo	*Allocyttus verrucosus*	ALL		异海鲂			
white hake	*Urophycis tenuis*	HKW		白長鰭鱈	Merluche blanche	Налим нитеперый белый	Locha blanca
witch flounder	*Glyptocephalus cynoglossus*	WIT		美首鲽	Plie cynoglosse	Камбала длинная (красная) атлантическая	Mendo
wreckfish	*Polyprion* spp.	HAU		美洲多鋸鱸	Cernier	окунь бурый каменный	Chernoda
yellowfin sole	*Limanda aspera*	YES		糙鰈	Limande du Japon	Камбала желтоперая	Limanda japonesa
yellowtail flounder	*Limanda ferruginea*	YEL		大西洋鰈	Limande à queue jaune	Камбала желтохвостая (=лиманда желтохвостая)	Limanda
yellowtail kingfish	*Seriola lalandi*	YTC		黄尾鰤	Sériole chicard	Сериола полосатая	Medregal rabo amarillo
Invertebrates							
Antarctic krill	*Euphausia superba*	KRI		南极大磷虾	Krill antarctique	Криль антарктический	Krill antártico
Arctic surfclam	*Mactromeris polynyma*	IFM					Coquina antárctica
Argentine shortfin squid	*Illex argentinus*	SQA			Encornet rouge argentin	Иллекс аргентинский	Pota argentina
blue and red shrimp	*Aristeus antennatus*	ARA			Crevette rouge		Gamba rosada
deep-sea red crab	*Chaceon erytheiae*						
deepwater red crab (2)	*Chaceon affinis*	KEF	سرطان أحمر لأعماق البحر	深海红蟹	Crabe rouge de profondeur		Cangrejo rey
deepwater rose shrimp	*Parapenaeus longirostris*	DPS	إيربيان وردية أعماق المياه	长额拟对虾	Crevette rose du large	Креветка розовая глубоководная	Gamba de altura
giant red shrimp	*Aristaeomorpha foliacea*	ARS			Gambon rouge		Gamba española
horned octopus	*Eledone cirrhosa*	EOI	أخطبوط مُقرَّن شائع	角爱尔斗蛸	Élédone commune		Pulpo blanco

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Iceland scallop	*Chlamys islandica*	ISC			Peigne islandais		Peine islándico
jumbo flying squid	*Dosidicus gigas*	GIS			Encornet géant	Кальмар Гумбольдта (=кальмар гигантский)	Jibia gigante
king crab	*Paralomis* spp.	PAI					
northern shortfin squid	*Illex illecebrosus*	SQI			Encornet rouge nordique	Иллекс американский	Pota norteña
northern shrimp	*Pandalus borealis*	PRA			Crevette nordique	Креветка северная	Camarón norteño
Norway lobster	*Nephrops norvegicus*	NEP			Langoustine		Cigala
nylon shrimp	*Heterocarpus reedi*	CHS			Crevette nylon chilienne		Camarón nailon
Patagonian scallop	*Zygochlamys patagonica*	ZYP	محارة مروحية باطاغُونيَّة	巴塔哥尼亚扇贝	Peigne de Patagonie		Pecten patagónico
red coral	*Corallium* spp.	COR			Coraux précieux nca		Corales preciosus nep
snow (=queen) crab	*Chionoecetes opilio*	CRQ			Crabe des neiges		Cangrejo de las nieves
tanner crab	*Chionoecetes bairdi*	CVB					
veined squid	*Loligo forbesii*	SQF	ذو الأذرع العشر مُعَرَّق	纹理枪乌贼	Encornet veiné		Calamar veteado
Mammals							
killer whale	*Orcinus orca*	KIW	الحوت السَّفّاح	虎鲸	Orque	Косатка	Orca
sperm whale	*Physeter macrocephalus*	SPW	عنبر	抹香鲸	Cachalot	Кашалот	Cachalote

(1) possibly includes other *Centroscymnus* spp. in the Indian Ocean.
(2) may include other *Chaceon* or *Geyron* spp. (southeast Atlantic).
Source: http://www.fao.org/fishery/collection/asfis/en [Cited 1 December 2019].