OPEN OCEAN FISHERIES FOR DEEP-WATER SPECIES

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Introduction

Deep-water fisheries are considered to be those that exploit fish or shellfish that habitually live at depths greater than 400 m. With the exception of some localized line fisheries around oceanic islands, such as for *Aphanopus carbo* (black scabbardfish) at Madeira in the Atlantic and for *Ruvettus* in Polynesia, the fisheries are mostly of recent origin. The deep-water fisheries of the continental slopes only developed in the 1960s when Soviet trawlers discovered and exploited concentrations of roundnose grenadier (*Coryphaenoides rupestris*) off Canada and Greenland. At the same time, the Soviet fleet was exploiting similar resources in the North Pacific. Since then, despite a decline in Russian landings, deep-water fisheries have continued to expand on a global scale. Some of these fisheries target species that had never previously been exploited, such as orange roughy (*Hoplostethus atlanticus*). Some species have a depth range that extends from the shallow continental shelf depths into deeper water, and there is an increasing trend for the fisheries on these species to extend into deeper water and exploit all stages of the life history. Examples of such species in the North Atlantic are Greenland halibut (*Reinhardtius hippoglossoides*), anglerfish (*Lophius* spp.) and deep-water redfish (*Sebastes mentella*).

The United Nations Food and Agriculture Organization (FAO) has divided the world's oceans into statistical areas (**Figure 1**) and for some species there are data on landings. However, in many countries deep-water species are frequently landed unsorted in grouped categories that sometimes makes it difficult, if not impossible, to specify a proportion of the catch as deep-water. For example, many sharks are grouped and the term 'sharks various' can include inshore, deep-water, and oceanic pelagic species.

Deep-water fishes are generally perceived as being slow-growing and having a high age at first maturity and a low fecundity, all of which contribute to making them susceptible to overexploitation. In a new fishery the initial catch rates will be high, but,

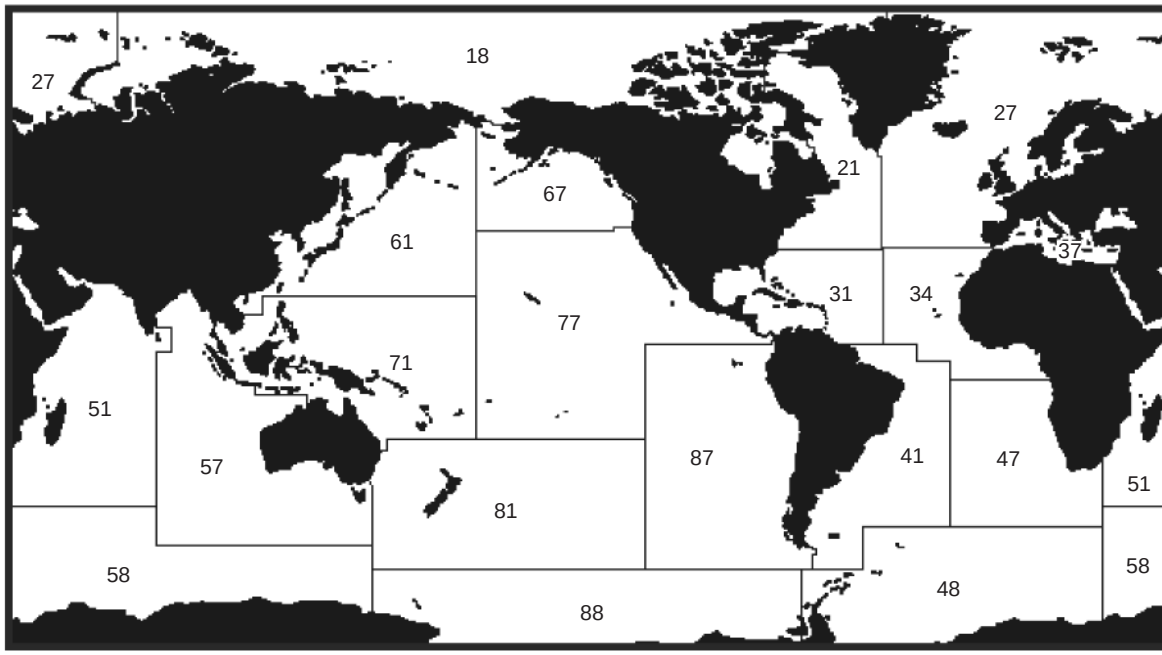

Figure 1 Map showing major fishing areas used by FAO for statistical purposes. The numbered areas are referred to by name in the text and **Figures 2–7** and can be identified by reference to **Table 1**. (From Gordon, 1999.)

as the accumulated biomass of older fish is removed, the catch rates will decrease. For some species the sustainable yield may be only 1–2% per year of the pre-exploitation biomass. Few deep-water fisheries are managed, but where they are managed an objective has often been to maintain the stock at above 30% of the virgin biomass. Some deep-water species, such as sharks and orange roughy, have a global distribution, while others, such as roundnose grenadier, *Sebastes* spp. and Patagonian toothfish (*Dissostichus eleginoides*), are widely distributed within different oceans. Virtually nothing is known about the stock structure of most deep-water species and this can cause problems when developing management strategies. The following examples have been chosen to illustrate some of the problems associated with the sustainable exploitation and management of deep-water fisheries.

Black Scabbardfish (*Aphanopus carbo*) (Figure 2)

One of the longest-established deep-water fisheries is the fishery for black scabbardfish in the eastern North Atlantic. It began as a longline fishery around the oceanic island of Madeira and probably originates from the seventeenth century. Records of landings exist from about the 1930s, but because of the artisanal nature of the fishery these may be unreliable. At the beginning the fishery was prosecuted from open boats using vertical longlines set at about 1000 m depth and which were hauled by hand. However, in recent years the fishery has evolved and now uses larger vessels, mechanized line haulers and horizontal floating longlines. As a result the landings have been increasing, partly as a result of increasing efficiency and also because of the discovery of new fishing grounds farther from the islands. In 1983 a longline fishery for black scabbardfish developed off mainland Portugal and catches increased rapidly. When a mixed bottom-trawl fishery developed on the continental slope to the west of the British Isles in the 1990s black scabbardfish was an important bycatch and landings increased considerably. There is little doubt that the catch per unit of effort (CPUE) in the trawl fishery is decreasing and in 2000 the International Council for the Exploration of the Sea (ICES) recommended a 50% decrease in fishing effort. However, there is a lack of basic biological knowledge on which to base any effective management. The eggs, larvae, and smallest juveniles of black scabbardfish are unknown. Estimated ages range from about 8 to over 20 years, but without information on the juvenile stages these cannot be validated. Mature female fish are found around Madeira, off mainland Portugal, and probably also from the Azores and northward along the Mid-Atlantic and Reykjanes Ridges. To the west of the British Isles the fish are all immature. One hypothesis to explain this distribution is that there is a single north-eastern Atlantic stock and that the adult fish spawn in the southern areas and the subadults migrate northward on a feeding migration. Studies of the diet of the subadult fish in the northern areas have shown that they feed on other fish such as blue whiting (*Micromesistius poutassou*) and argentine (*Argentina silus*) that shoal along the upper continental slope. If this hypothesis proves to be correct, effective management will have to take into account the three established fisheries and another that is developing in the Mid-Atlantic. An important by-catch of the longline fisheries for black scabbardfish are deep-water squalid sharks, such as *Centroscymnus coelolepis*, *Centrophorus squamosus*, and *Centrophorus granulosus*. Deep-water shark fisheries have their own problems (see below).

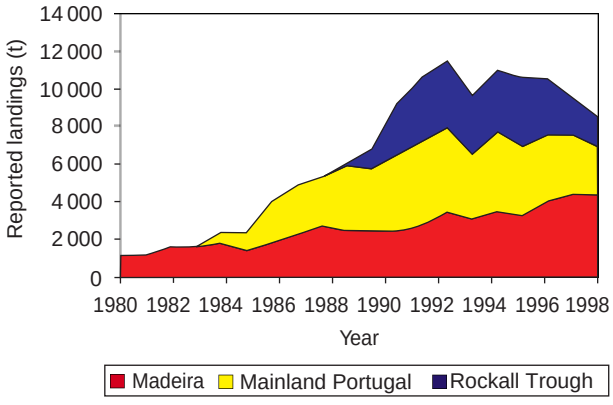

Figure 2 The reported landings (tonnes) of black scabbardfish (*Aphanopus carbo*) caught by longline around Madeira and off mainland Portugal and by bottom trawl in the Rockall Trough (all north-east Atlantic).

Roundnose Grenadier (*Coryphaenoides rupestris*) (Figure 3)

Concentrations of roundnose grenadier were discovered along the continental slope of the western North Atlantic north of 50°N in the late 1950s. This led to fishery investigations and exploratory voyages by Russia, the then German Democratic Republic, and Poland, and also coincided with the introduction of the large factory-freezer stern trawlers. The first directed fishery for roundnose grenadier was by Russia in the north-west Atlantic in the mid 1960s. This fishery began off the north-west of Newfoundland, and later extended

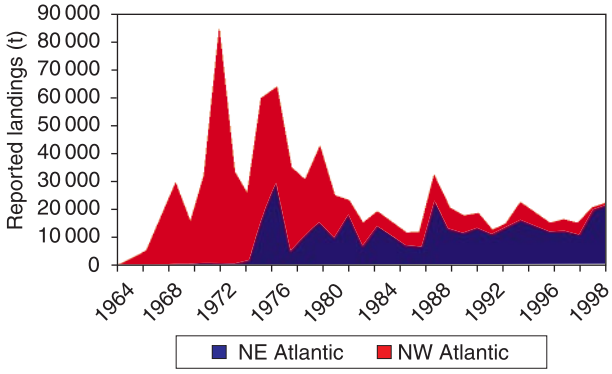

Figure 3 The reported landings (tonnes) of roundnose grenadier (*Coryphaenoides rupestris*) caught by bottom trawl in the north-east Atlantic and the north-west Atlantic (FAO statistical areas).

northwards to Labrador, Baffin Island and western Greenland. The fishery developed rapidly, reaching a peak of over 83 000 t in 1971. The subsequent decline in the fishery has often been ascribed to overexploitation and, while this might be an important factor, other contributory factors are undoubtedly the establishment of 200-mile national fishery zones, changes in the allowable by-catches in the Greenland halibut fishery, and probably some misreporting of initial catches. Scientific research on roundnose grenadier lagged far behind the fishery and it was not until 1975 that a precautionary total allowable catch (TAC) was imposed. However, the landings continued to decline and were soon well below the level of the TAC, which was also being steadily reduced. It was only in the 1990s that landings reached the level of the TAC as a result of the by-catch of the European trawlers fishing for Greenland halibut in international waters around the Flemish Cap.

A similar fishery developed in the international waters of the eastern North Atlantic (including the Mid-Atlantic and Reykjanes Ridges) in about 1973. Historically, the largest catches were from Russian vessels fishing the southern part of the Reykjanes Ridge. The landings peaked in 1975 and have fluctuated ever since. ICES has expressed concern that some of the catches in international waters are not being reported. By-catches of other species in these mixed, bottom-trawl catches have also been inadequately reported. In the early 1970s German trawlers and later French trawlers began to exploit spawning aggregations of blue ling (*Molva dypterygia*) in the northern parts of the Rockall Trough. Some French trawlers, which traditionally fish along the shelf edge for species such as saithe (*Pollachius virens*), began to move onto the upper and mid-continental slope of the Rockall Trough to exploit blue ling and by 1989 were beginning to land a by-catch of species such as roundnose grenadier, black scabbardfish, deep-water sharks, and several other less abundant species. As the fishery evolved it moved into deeper waters and soon roundnose grenadier was a target species in its own right. The landings have remained fairly constant in recent years, but there is good evidence to suggest that the CPUE has decreased. The landings have been maintained by increasing fishing effort and efficiency, moving into new areas and deeper water, and discarding fewer of the smaller fish. In 2000 ICES recommended a 50% cut in fishing effort and the European Commission proposed a precautionary TAC on this and other deep-water species in 2001. However, the fisheries ministers deferred the Commission's proposals and the fisheries remain unregulated. Almost nothing is known about the stock structure of roundnose grenadier and, although knowledge of the biology is improving, the data for analytical, age-based stock assessments is lacking. It is probable that the stocks in the area of the Rockall Trough that is under national jurisdiction are part of a larger stock around the Rockall and Hatton Banks that is in international waters. The lack of any regulation in international waters will diminish the value of any management measures introduced in waters under coastal state jurisdiction. There is also the issue whether TACs are an appropriate management tool for mixed fisheries. The problems of discarding over-quota marketable species, so-called high grading, etc., are all well documented in shelf fisheries, but the additional problem of a changing catch composition with depth in deep-water fisheries is something that will be difficult to incorporate into a management scheme.

Scorpaenid Fisheries (*Sebastes* spp. and *Sebastolobus* spp.) (Figures 4 and 5)

The trawl fisheries for redfishes are among the most important deep-water fisheries of the North Atlantic. In the north-western Atlantic the landings comprise a mixture of three species (*Sebastes marinus*, *S. fasciatus*, and *S. mentella*), but only *S. mentella* is a truly deep-water species. Because the landings are not separated into species, it is impossible to assess the importance of the deep-water component of the catch. The fishery peaked at almost 400 000 t in the mid-1950s and, except for an increase in the 1970s, has been steadily declining. The peaks in landings represent times when different nations entered the fishery but, at the present time, the fishery is

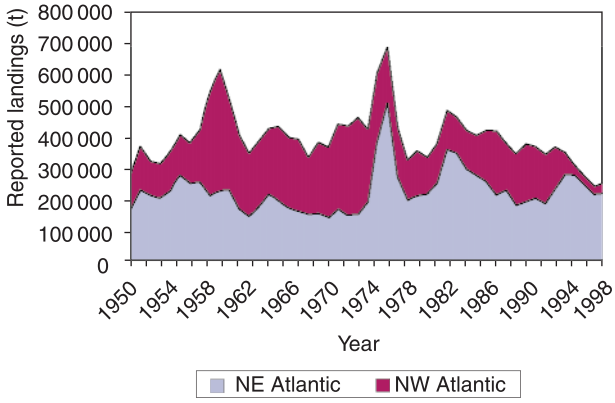

Figure 4 The reported landings (tonnes) of redfish (*Sebastes* spp.) caught by trawl in the north-east Atlantic and the north-west Atlantic (FAO statistical areas).

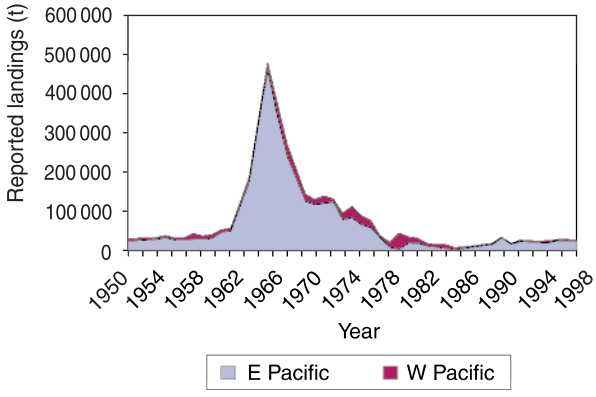

Figure 5 The reported landings (tonnes) of Pacific Ocean perch (*Sebastes alutus*) caught by trawl in the east and west Pacific (FAO statistical areas).

dominated by Canada. It appears that this fishery is now in serious decline, which is perhaps not surprising given the high level of exploitation, the slow growth, the high age at first maturity and the viviparous mode of reproduction. The mean length of fish caught by research vessels has been declining steadily. In the eastern North Atlantic the landings are comprised of two species (*Sebastes marinus* and *S. mentella*). Recently the landings of redfish by some countries have been partly apportioned into the two species on the basis of research surveys. *S. mentella* is the deep-water species, but these data do not give a true indication of the likely proportion of this species to the total catch of the whole region. However, there can be little doubt that the trend in recent years has been to increasingly exploit *S. mentella* in deeper water and for an overexploitation of all stocks. A longline fishery for so called 'giant redfish' developed in 1996 on the Reykjanes

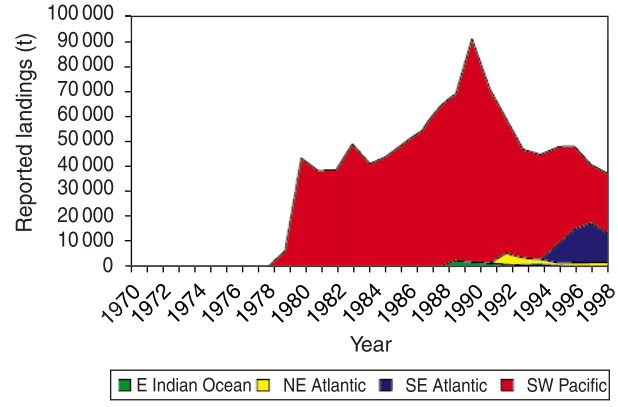

Figure 6 The reported landings (tonnes) of orange roughy (*Hoplostethus atlanticus*) caught by trawl in the south-west Pacific (New Zealand and eastern Australia), the eastern Indian ocean (Australia), the south-east Atlantic and the north-east Atlantic.

Ridge but only lasted for that year as a profitable fishery.

In the North East Pacific the fishery for Pacific Ocean perch (*Sebastes alutus*) began in 1946 and, after a slow period of development, the landings peaked at over 460 000 t in 1965 and then steadily declined over the next decade so that they now they range between about 10 000 to 30 000 t (**Figure 5**). In the North West Pacific the fishery for Pacific ocean perch is on a smaller scale but peaked in the 1970s and has since declined. This species has a range from the outer shelf to the upper slope and most of the fishery is on the outer shelf at about 200–300 m.

There are several scorpaenid fishes that extend from the outer shelf to the continental slope and, with the exception of the Pacific Ocean perch, the FAO statistics do not separate them at the species level. However, many of the stocks in shallower waters have become depleted and the fishery has progressively moved into deeper waters to exploit several species. These include in the east the long spine thornyheads (*Sebastolus altivelis*) and splitnose rockfish (*Sebastes diplopoa*) and in the west the longfin thornyhead (*Sebastolobus macrochir*), the shortspine thornyhead (*S. alascanus*), the rougheyed rockfish (*Sebastes aliutianus*) and the osaga (*S. iracundus*).

The Orange Roughy (*Hoplostethus atlanticus*) (Figure 6)

The orange roughy is probably the most frequently cited example of an exploited deep-water fish partly because it is an extreme example of all the features

than can lead to over-exploitation; a life span of >100 y, high age at first maturity (~ 25 y), and a relatively low fecundity. It also has many qualities that make it a highly marketable commodity. It tends to aggregate in large numbers around seamounts, pinnacles, and steep slopes and with sophisticated fishing techniques these stocks can be fished down very rapidly: a type of fishing sometimes referred to as 'mining'.

The most important fishery for orange roughy is around New Zealand. This trawl fishery, at depths from about 700 to 1200 m, began in the late 1970s and expanded rapidly, with landings exceeding 60 000 t per annum in the late 1980s and early 1990s. Since then landings have declined to about 25 000 t. The dense spawning and feeding aggregations were systematically fished down and the fishery was maintained by the continual discovery of new fishing grounds, mainly on the extensive deep-water plateaus and rises that surround New Zealand. The present level of landings is composed of a reduced catch from established fisheries and higher catches from new areas.

The Australian fishery for orange roughy extends along the slope of south-eastern Australia, around Tasmania, and extends up to New South Wales. Fishing began in 1982 as part of a general slope fishery and it was not until 1986 that dense aggregations were found off Tasmania and a directed fishery was established. Between 1986 and 1988 the landings of orange roughy ranged between about 4600 and 7200 t per annum. New non-spawning aggregations and a new spawning aggregation resulted in a dramatic increase in catches from 26 000 t in 1989 to 41 000 t in 1990. Since then the landings have declined. FAO reports the landings of this area together with the New Zealand Fishery (south-west Pacific). A smaller fish fishery is reported by FAO in the eastern Indian Ocean and landings have steadily decreased from initial levels of about 2000 t in 1989.

In the north-eastern Atlantic, French trawlers began landing orange roughy from deep water to the west of the British Isles in 1991. Although there is still a degree of secrecy associated with this fishery, there is little doubt that it takes place at greater depths (down to about 1700 m) than the multi-species trawl fishery for roundnose grenadier (see above) and most probably in areas of steep slopes and seamounts. The landings peaked in 1992 and the fishery has subsequently declined in the Rockall Trough (ICES Sub-area VI). Landings from west of Ireland (ICES Sub-area VII) have remained fairly constant, probably as a result of the sequential discovery and fishing down of new aggregations. In the international waters of the north-eastern Atlantic, a Faroese vessel has been fishing on the Mid-Atlantic Ridge and other offshore banks and seamounts. There have also been spasmodic catches by Iceland on the Reykjanes Ridge.

The New Zealand orange roughy fishery, because of its economic importance, has been the subject of considerable research in recent years. Nevertheless, the rapid development of the orange roughy fishery far outpaced the scientific knowledge of the fish and the stocks. The initial quotas were essentially precautionary, to allow time for an assessment to be carried out. These assessments were based on random stratified trawl surveys but, because there was a lack of knowledge about the great age and low productivity and the stock discrimination of this fish, some inappropriate assumptions were made. As a result the quotas set in the early years of the fishery, mainly for the Chatham Rise and Challenger Plateau, were too high and the stocks were over-exploited. In recent years there has been a marked improvement in the knowledge of the biology of the species, although the estimates of very high ages continue to be controversial. Improved stock assessment, using a variety of methods, and the application of genetics to stock discrimination have allowed more realistic TACs to be implemented. For example, on the Chatham Rise the TAC was decreased from 33 000 t in 1990 to 7000 t in 1996. By 1998 the stock was considered to be at 15–20% of virgin biomass but rebuilding. However, in other areas quotas continue to be reduced and on the Challenger Plateau, once a major fishery, the quota for the 2000/2001 fishing year has been reduced to 1 tonne, thereby effectively closing the fishery. The Australian fishery is also managed by quotas and these have been reduced drastically since the start of the fishery. The fishery in the north-east Atlantic remains totally unregulated.

Deep-water Sharks

Deep-water sharks are landed as a by-catch of many deep-water fisheries and there are some targeted fisheries. In some fisheries, such as in the bottom-trawl fishery for roundnose grenadier in the north-eastern Atlantic, only some of the shark species that are caught are landed. The rest are discarded, sometimes after removal of the liver and/or the fins. The reported landings to FAO are, with a few exceptions, by grouped category and it is therefore difficult to estimate the true extent of the fishery. Deep-water sharks of small adult size or the juveniles of marketable species that are discarded are unlikely to survive. No records are kept of

discards and there have been few scientific studies of discarding.

Sharks are vulnerable to over-exploitation because of their longevity and slow growth. They have a high age at first maturity and a low reproductive rate per female as a result of the long embryonic development for oviparous and viviparous species, from several months up to about two years. The majority of deep-water species might have biennial or even triennial reproductive cycles.

Several fisheries that target sharks, such as the longline fishery for gulper shark (*Centrophorus granulosus*) off mainland Portugal and the kitefin shark (*Dalatias licha*) at the Azores, have declined rapidly after a few years and are good examples of the vulnerability of these stocks. The CPUE of the combined catches of leafscale gulper shark (*Centrophorus squamosus*) and the Portuguese dogfish (*Centroscymnus coelolepis*) from the trawl fishery to the west of the British Isles has declined by about 50% in less than ten years. Longlining is often presented as a more selective and environmentally friendly method of exploiting deep-water fish resources. However, many exploratory surveys have shown that there can be a high, perhaps unacceptable, by-catch of unwanted sharks.

Patagonian Toothfish (*Dissostichus eleginoides*) (Figure 7)

The main deep-water fishery in the southern oceans is for the Patagonian toothfish. It is widely distributed in the area and it is caught by longline at depths down to 2000 m or more. The reported landings are probably unreliable as there is thought to be illegal fishing in the area. The significant landings are from the Atlantic (FAO Area 48) and Indian Ocean (FAO Area 58) sectors.

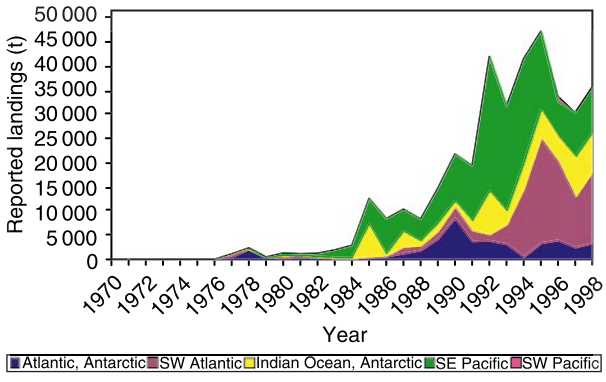

Figure 7 The reported landings (tonnes) of Patagonian toothfish (*Dissostichus eleginoides*) caught in the south-west Pacific (New Zealand and eastern Australia), the south-east Pacific, the Indian and Atlantic Ocean sectors of Antarctica (Australia) and the south-west Atlantic.

In the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) area the toothfish is managed by TAC with additional technical measures, some of which are designed to limit the accidental capture of seabirds attracted to the baited hooks as the lines are being set.

Other Deep-water Fisheries

The above examples were chosen to illustrate some of the different aspects of deep-water fisheries and the associated problem of managing what are generally considered to be fragile resources. There are many other deep-water species that are either targeted or are a by-catch of other deep-water fisheries. **Table 1** gives some of the important deep-water species that are clearly identifiable in published FAO statistics by statistical area. This list excludes many species that are recorded under grouped categories or where most of the fishery takes place on the continental shelf.

Ecosystem Effects

There is a growing concern, in part resulting from new technologies that allow direct observation, about the effects of fishing on the ecosystem and the probability that the deep-water ecosystems will be particularly susceptible to damage and will take a long time to recover. There is an expanding literature on the physical effects of fishing gear, especially trawls, on the sea bed in shallow water. In deeper water there are reports from photographic surveys of trawl marks in soft sediments, but little information on the effects at the biological level. Trawl damage to hard bottoms such as deep-water reefs and seamounts has been documented and reefs of the deep-water coral *Lophelia* off Norway and some seamounts off Australia and New Zealand are now protected. Discarding of species of no commercial value can represent a very high proportion of the catch. None of these discards will survive the trauma of being brought to the surface from great depths. Deep-water fishes generally have fragile skins and it is very probable that most fish entering the trawl and escaping through the meshes will not survive. The impacts of these discards and unseen mortalities on the ecosystem are unknown. The effect of the selective removal of top predators is also largely unknown.

Table 1 Deep-water fish species that are listed by area in FAO fishery statistics

		Northwest Atlantic	Northeast Atlantic	Central Atlantic	Mediterranean	Southwest Atlantic	Southeast Atlantic	Atlantic Antarctic	Eastern Indian Ocean	Indian Ocean Antarctic	Northwest Pacific	Northeast Pacific	Central Pacific	Southwest Pacific	Southeast Pacific	Pacific Antarctic
	FAO Statistical Area	*21*	*27*	*31 & 34*	*37*	*41*	*47*	*48*	*57*	*58*	*61*	*67*	*71 & 77*	*81*	*87*	*88*
Common name	Scientific name															
PISCES																
Scyliorhinidae																
Blackmouth dogfish	*Galeus melastomus*		+		+											
Squalidae																
Portuguese dogfish	*Centroscymnus coelolepis*		+													
Leafscale gulper shark	*Centrophorus squamosus*		+													
Kitefin shark	*Dalatias licha*		+													
Argentinidae																
Argentine	*Argentina silus*		+													
Deep-sea smelt	*Glossanodon semifasciatus*										+					
Congridae																
Conger eel	*Conger conger*		+													
Ophidiidae																
Pink cusk eel	*Genypterus blacodes*					+									+	
Kingclip	*Genypterus capenensis*						+									
Macrouridae																
Roundnose grenadier	*Coryphaenoides rupestris*	+	+													
Roughhead grenadier	*Macrourus berglax*	+	+													
Pacific grenadier	*Coryphaenoides acrolepis*										+		+			
Longfin grenadier	*Coryphaenoides longifilis*										+					
Merlucciidae																
Hake	*Merluccius merluccius*		+		+											
Cape hakes	*Merluccius capenensis & M. paradoxus*						+									
Patagonian grenadier	*Macruronus magellanicus*					+								+		
Hoki	*Macruronus novaezelandiae*															
Gadidae																
Greater forkbeard	*Phycis blennoides*		+		+											
Blue ling	*Molva dypterygia*		+													
Blue whiting	*Micromesstius poutassou*		+		+											
Southern blue whiting	*Micromesistius australis*					+								+	+	
Moridae																
Morid	*Laemonema longips*										+					
Berycidae																
Alfonsinos	*Beryx* spp.		+				+						+			
Trachichthyidae																
Orange Roughy	*Hoplostethus atlanticus*		+				+		+					+		
Polyprionidae																
Wreckfish	*Polyprion americanus*				+											
Pentacerotidae																
Pelagic armourhead	*Pseudopentaceros wheeleri*												+			
Oreosomatidae																
Smooth oreo	*Pseudocyttus maculatus*													+		
Black oreo	*Allocytus niger*													+		
Apogonidae																
Deep-water cardinal fish	*Epigonus telescopus*		+											+		
Sparidae																
Blackspot seabream	*Pagellus bogaraveo*		+		+											
Trichiuridae																
Black scabbardfish	*Aphanopus carbo*		+	+												
Scorpaenidae																
Bluemouth	*Helicolenus dactylopterus*		+		+											
Pacific Ocean perch	*Sebastes alutus*										+	+				
Redfish	*Sebastes* spp	+	+													
Rockfishes	*Sebastolobus* spp.										+	+				

Table 1 *Continued*

		Northwest Atlantic	*Northeast Atlantic*	*Central Atlantic*	*Mediterranean*	*Southwest Atlantic*	*Southeast Atlantic*	*Atlantic Antarctic*	*Eastern Indian Ocean*	*Indian Ocean Antarctic*	*Northwest Pacific*	*Northeast Pacific*	*Central Pacific*	*Southwest Pacific*	*Southeast Pacific*	*Pacific Antarctic*
	FAO Statistical Area	*21*	*27*	*31 & 34*	*37*	*41*	*47*	*48*	*57*	*58*	*61*	*67*	*71 & 77*	*81*	*87*	*88*
Anoplopomatidae																
Sablefish	*Anoplopoma fimbria*										+	+	+			
Nototheniidae																
Patagonian toothfish	*Dissostichus eleginoides*					+		+		+				+	+	+
Pleuronectidae																
Dover sole	*Microstomus pacificus*											+				
Greenland halibut	*Reinhardtius hippoglossoides*	+	+													
CRUSTACEA																
Penaeidae																
Rose shrimp	*Parapenaeus longirostris*		+	+												
Aristeidae																
Blue and red shrimp	*Aristeus antennatus*			+												
Nephropidae																
Norway lobster	*Nephrops norvegicus*		+	+												
Geryonidae																
Deep-water red crab	*Chaceon maritae*			+												

See also

Deep-sea Fishes. Demersal Fishes. Demersal Species Fisheries. Mesopelagic Fishes. Open Ocean Fisheries for Deep-water Species. Open Ocean Fisheries for Large Pelagic Species. Salmon Fisheries: Pacific.

Further Reading

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