C3. DEEPWATER FISHERIES

by Ross Shotton *

THE DEEPWATER HABITAT

The deep-seas are the largest habitat on earth. The area over 4000 m in depth covers 53 percent of the sea's surface or 38 percent of the world's surface. The continental slopes alone occupy 8.8 percent of the world's surface, compared to 7.5 percent for the continental shelf and shallow seas (Merrett and Haedrich 1997). The deep-sea can be classified into four zones: the mesopelagial is uppermost and ranges from 200 to 1 000 m; the bathypelagic occupies the 1 000–4 000 m depth zone; the abyssopelagic goes from 4 000 to 6 000 m and the hadal zone mentioned for completeness, is the habitat of the deep ocean trenches (See Figure C3.1). From a demersal fishery, the deepwater region can be taken as the continental slopes, starting at the shelf break and corresponding to the mesopelagic and bathypelagic and , beneath, the continental rise which extends down to the abyssal planes at around 6000 m. Complicating this picture are the existence of seabed features that may rises thousands of metres above the surrounding areas–seamounts, or form regions of "hills" or knolls.

The main thermocline rarely extends below 1200 m; below this the temperature falls to around 2ºC and even lower in areas where water masses sink, such as the Weddel Sea and high-latitude areas in the NE Atlantic. Active current effects are encountered to at least mid-slope depths of about 800 m, a result of eddies and turbulence caused by the poleward flow of western boundary currents. Wind-driven surface currents can also cause mid-depth upwelling of water and species and down welling of surface waters and species. On the seabed, bottom-sea friction can cause cross-shelf water movement and vertical movement of water.

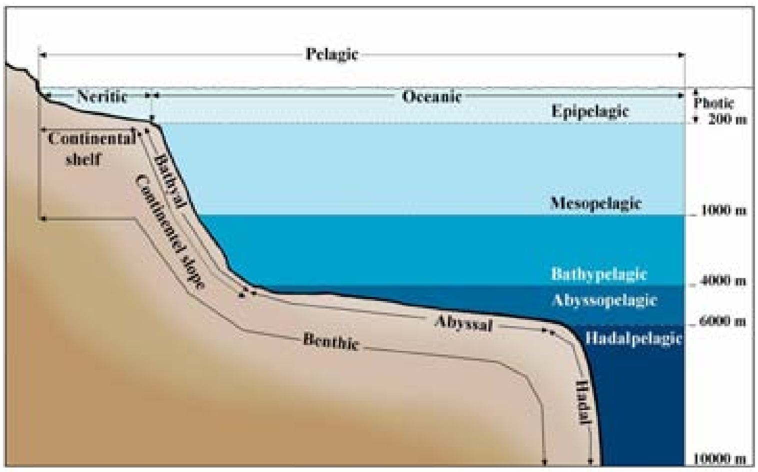
No light penetrates beyond 1 000 m and even at depths of 150 m light intensity is reduced to 1 percent of that at the surface insufficient for photosynthesis. Thus fish in deeper layers depend on organic material convected downward; this can happen in various ways. Dead phytoplankton and nekton sink, and though much is consumed as it sinks, sufficient of it enters the deepwater to sustain much of the deepwater fauna. Many species undergo extensive diel vertical migrations, feeding near the surface and descending during the day, presumably to avoid predation in the surface waters. In this way, surface production is cascaded through progressively deeper layers though the concentration of organic material decreases exponentially with depth. Organic material from large carcasses sinking to the seafloor, e.g. dead whales, and sulpha-based organic production associated with deep-sea seafloor hot-water vents are of relatively minor importance.

It is now known that seasonal effects in the surface layers are transferred into even the deeper regions of the oceans so that despite the physical uniformity of the deep oceans, an annual production signal exists resulting in seasonal migrations and reproductive cycles in deep-sea fauna.

WHAT ARE THE DEEPWATER FISHES?

Given the continuity of the oceans as an ecosystem, any depth-based zonation will be arbitrary. Some workers use 500 m as the start of the deepwater habitat, others consider deepwater

Figure C3.1. Depth Zones of the Oceans



fishes to be those living at depths greater than 400 m - no rigid definition of what are deepwater fishes has been found to be always acceptable. However, deepwater fishes can be categorized into mesopelagic, bathypelagic and benthopelagic categories. Mesopelagic and bathypelagic species are true pelagic fish, generally of small adult size and unlikely to be exploited on a commercially scale. Mesopelagic fishes, such as lantern fishes (Myctophidae) and cyclothonids (Gonostomatidae) live beneath the photic zone to approximately 1000 m depth. Bathypelagic fishes live below 1000 m and are usually highly adapted to life in a food-poor environment. The benthopelagic species live on, or close, to the bottom, a zone now known to be differentiated in its biological characteristics.

Here, deepwater species are defined as those beyond and below the depth of the continental shelf, i.e. those inhabiting the continental slopes and below. The behavioural characteristics of many "deepwater" species further complicate a search for an easy and useful definition. Many deepwater species migrate toward the surface at night returning during the day thereby forming a trophic link between surface waters and the benthopelagic fishes when these latter prey upon fish returning from the surface layers. Other fishes make this diel migration themselves, feeding in the surface layers and then descending, presumably to avoid being eaten themselves. Some species only inhabit deepwaters in their adult stage, and may be exploited during both their shallow - and deepwater phases - complicating the interpretation of whether such catches be defined as deepwater or not.

The first existing deepwater demersal species were present around 80 million years ago and, in order of their occurrence in the fossil record, were the Holosauridae, Bythitidae, Ophidiidae (cusk eels and brotulas), Macrouridae (rat-tails and grenadiers), Scorpaenidae (rockfishes), Trachichthyidae, and most recently, Notocanthidae and Moridae (morid cods) (Andriyashev, 1953). Because the demersal fishes are distributed according to depth, those inhabiting the slope and rise are spread along ribbon-like bathymetric-defined regions around the perimeters of the oceans. Where deepwater pelagic species impinge on these habitats feeding opportunities are created for both groups.

While most of these families occur world-wide, the existence of deepwater basins bounded by the continents and oceanic ridges has resulted in regional differences that are believed to have arisen from continental drift and subsequent ocean formation. Another important feature of deepwater fishes is that much remains unknown– new discoveries continue, e.g. recently that of a 4.5 m 750 kg shark (megamouth shark) and a six-gilled ray, both representing new taxonomic families. Indeed, deepwater elasmobranchs are one of the groups of particular conservation concern even when not exploited, given their low numbers, their late maturity, low fecundity and intermittent reproduction.

Though there have been some traditional deepwater fisheries (the drop line fishery for black scabbard fish (*Aphanopus carbo*) in Madeira and the Azores is one of the more interesting), the most important commercially are those that are harvested by trawling. Many of these occur in association with sea mounts and seafloor ridges while others have been taken at shallower depths in the past but fishing has extended in to deeper waters as deepwater fishing technology has improved and stocks have been fished down at shallower depths.

Important species that form deepwater aggregations include orange roughy (*Hoplostethus atlanticus*) and the oreos (*Allocyttus* spp., *Neocyttus* spp. *Pseudocyttus* spp., etc), which are often fished together, alfonsinos (*Beryx spp.*) in lower latitude fisheries, Patagonian toothfish (*Dissostichus eleginoides*) in Southern Ocean fisheries, pelagic armourhead (*Pseudopentaceros wheeleri*) and various species of Scorpaenidae found on both coasts of North America.

Away from seamounts, Gadiforme fishes such as the Macrouridae predominate. These species too tend to be slow growing but are not so "extreme" in their characteristics as those species associated with seamount fisheries. Other species that may be included in this group are sablefish (*Anoplopoma fimbria*), Greenland halibut (*Reinhardtius hippoglossoides*), morids (Moridae), cusk-eels (Brotulidae) and hakes (Merlucciidae). Some of these species were thought by many to be unmarketable but with effective marketing and careful processing (failure to properly remove all surface waxes from orange roughy fillets during processing can cause diarrhoea) even the sceptics have been surprised at the market penetration that has been achieved by many deepwater species.

Orange roughy

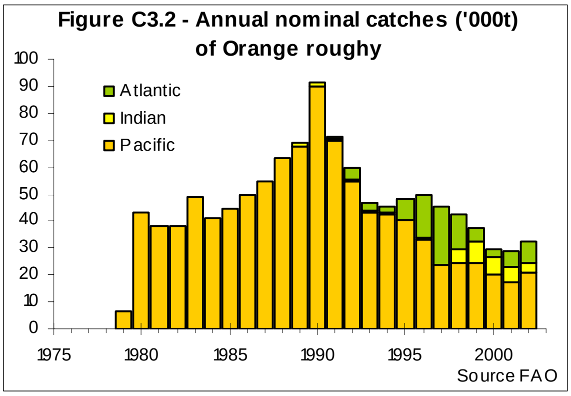


Figure C3.2 - Annual nominal catches ('000t) of Orange roughy

The Orange Roughy (*Hoplostethus atlanticus*) (Figure C3.2), is a Trachichthyidae found in the North and south Atlantic, Southern Indian Ocean, Tasman Sea, New Zealand sea, South Pacific. It is caught at depth over 800 m by fisheries that often target spawning aggregations associated with seamounts. The fraction of the resource present in other areas is unknown.

The slow growth and exceptional longevity of this species means that fisheries have depended on serial stock depletion. Recruitment appears to be episodic and high market demand stimulates exploitation. Rates of sustainable exploitation may be ≈5 percent of virgin biomass. This species exists as national, transboundary, straddling and high seas stocks. High sea management is confounded by the difficulty of obtaining required data.

Oreo dories

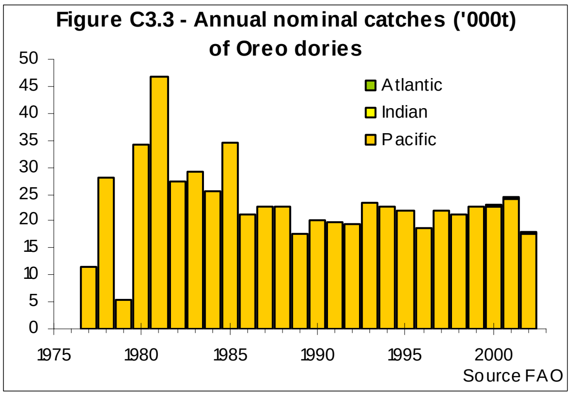


Figure C3.3 - Annual nominal catches ('000t) of Oreo dories

The Oreo dories (*Allocystus* spp. *Neocystus* spp. and *Pseudocustus* spp.) (Figure C3.3), are Oreostomadidae found close to the sea bed in deepwater and form large shoals over rough grounds near seamounts and canyons. The juveniles are pelagic and inhabit oceanic waters. They tend to be dispersed over smooth grounds. Their eggs float near the sea surface and the larvae also inhabit surface waters. In Australian waters, spiky oreo are more abundant at intermediate depths (600-800 m) and warty oreo, in deeper waters (900-1 200 m). Both species are benthopelagic feeders consuming salps, crustaceans, fish and squid.

Management of these fisheries on the high seas is confounded by lack of obtaining required data. Ageing data from Australia and New Zealand indicate that the maximum age for smooth oreo is 86 years and 153 years for black oreo. Natural mortality for smooth oreo has been estimated at 0.063 yr^{-1} and 0.044yr^{-1} for black oreo. Estimates from New Zealand indicates "MSY" to be of the order of 1.6 percent of B_0 if the population is not to be reduced to a biomass of less than 0.2 B_0 (probability <0.2). For operational reasons, where they are managed at all, smooth, black and spiky oreos may be managed as a single stock with the dangers this implies (Annala, Sullivan & O'Brien 1999).

Alfonsinos

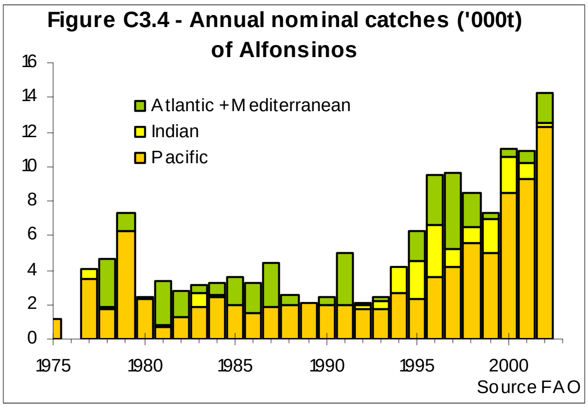


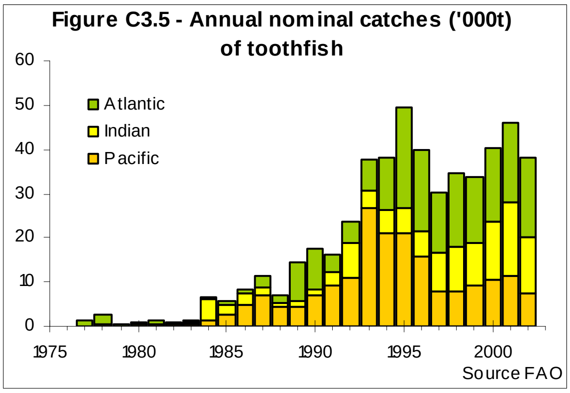
Figure C3.4 - Annual nominal catches ('000t) of Alfonsinos

The Alfonsinos (*Beryx splendens*), (Figure C3.4) are Bericidae that have a circumglobal distribution though they are generally not present in the northeast Pacific. They inhabit the outer shelf (180 m) and slope to at least 1 300 m depth, probably moving further from the bottom at night. *Beryx splendens* are caught in mid-water trawls over shallower seamounts, underwater ridges and on the slope edge between 300 and 500 m. The juveniles are pelagic. Genetic analysis suggests that there is, or has been, gene flow at the inter-oceanic scale and that this fishes have an ocean-wide population structure. There may be a Southern Ocean pool of juveniles that recruit northwards creating single genetic stocks of black and smooth oreo, but discrete ecological stocks with restricted post-recruitment dispersal

(Lehodey, Grandperrin & Marchal 1997, Smith 2000).

These species have a maximum recorded age of 17 years and become sexually mature at about 4 years of age. Natural mortality is estimated to be around 0.23. They thus offer most chance of sustaining deepwater fisheries that target them. Little is known about the local area stock structure of these species and it is believed, e.g. that the New Zealand fishery may be exploiting a wider South Pacific stock (Annala, Sullivan & O'Brien 1999).

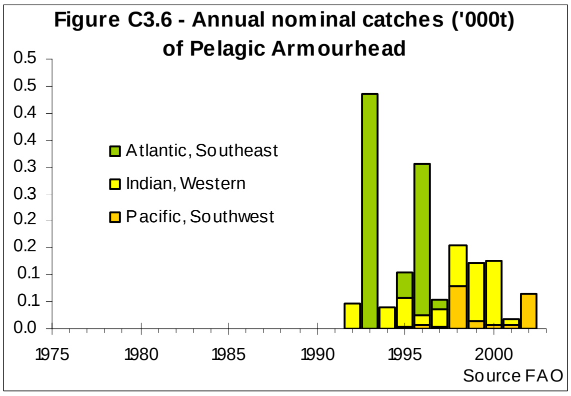
Toothfish



Toothfishes (*Dissostichus* spp.), (Figure C3.5) are Nototheniidae that have a circumpolar distribution within Antarctic and Southern Ocean waters. Patagonian toothfish (*D. eleginoides*) are found around southern South America and Antarctic toothfish (*D. mawsoni*) occurs in high latitudes, more currently in the Pacific region. The two species overlap between 60°S and 65°S and both occur to depths of 3 000 m. The northern limit for most populations of Patagonian toothfish is 45°S, except along the Chilean and Argentinean coasts where they may extend north in deeper colder water. Significant populations of Patagonian toothfish exist in the waters of, and adjacent to, the various sub-Antarctic islands and in the waters of Chile, Argentina, Uruguay and Peru.

The problem of illegal, unregulated and unreported fishing (IUU), while considerably reduced during the 2003-2004 season (6 342t in Statistical Area 41 and 3 701t in Area 87), remains the major concern. Further, catches of toothfish reported as taken outside of the CCAMLR management area, are believed by many to have been harvested from stocks within the management area. Past declines in toothfish stocks targeted by IUU fishing fleets have been fast and significant. For example, resources of toothfish in Prince Edward Islands (South Africa) have been reduced only a few percent of the pre-exploitation level.

Pelagic Armourhead

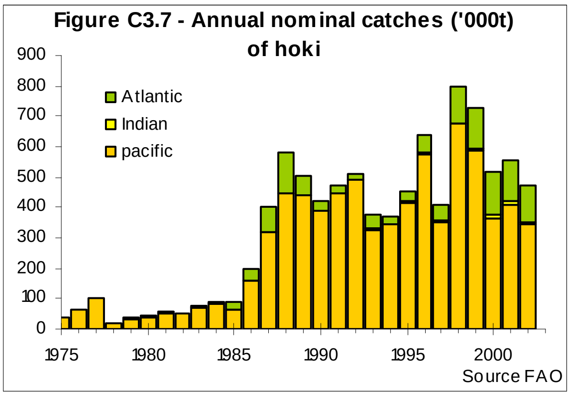


Pelagic Armourhead (*Pseudopentaceros wheeleri*), (Figure C3.6) are Pentacerotidae that inhabit Sea mounts, especially in the North Pacific but also other ocean areas which are caught by bottom trawl over seamounts.

Their fishery well illustrates the possible fate of seamount fisheries. Japanese and Russian vessels began trawling in the Emperor Seamount chain and the Northern Hawaiian Ridge areas in 1969. The total catch for the Russian vessels is not known but is estimated at over 133 400t in the period 1967–1977. Between 1969 and 1977, the Japanese sent two to five trawlers a year to this area and averaged catches of 22 800–35 100t a year. Ninety percent of the catch were pelagic armourhead. After catches fell to 5 800 - 9 900t between 1977 and 1982. The once dominant pelagic armourhead have been replaced by alfonsino (*Beryx splendens*), though the alfonsino stocks have never been as large as the pelagic armourhead they followed and there is no evidence that either of the fish stocks will recover to levels that will be commercially viable in the near future.

Hoki

Hoki (*Macruronus novaezelandiae*), (Figure C3.7) is a benthopelagic Macruronidae that usually lives near the bottom, but form mid-water aggregations for spawning. Large adult fish generally occur deeper than 400 m, while juveniles may be found in shallower water. Mid-water trawl fisheries target aggregations near canyons that are often close to coasts in areas of narrow continental shelves.



Stock structure is often uncertain and thus the matching of TACs to the areas of fisheries is a concern; in some areas bycatch of seal and other non-target species is a problem. Management experience in at least some jurisdictions indicates that this resource can be sustainably managed, though in the major global fishery for this species, in New Zealand, the TAC is changed from time to time as the size of the hoki stocks varies and has fluctuated over the last 15 years between 200 000 and 250 000t. In 2004, the TAC was reduced to 100 000t as the spawning stock has declined – caused, it is believed, by ENSO-related oceanographic events.

Other species

A further suite of deepwater, or at least slope species, have been the target of fisheries in many tropical regions. These can be targetted by small-scale deepwater fisheries usually along the shelf break and shelf slope wherever the continental shelf is relatively narrow and the fishing grounds are accessible to fishermen using small fishing boats. The principle species consist of members of the Lutjanidae, Serranidae, and Carangidae families and mostly importantly include the Eteline snappers (e.g. *Etelis coruscans* and *E. carbunculus*) and the jobfishes (e.g. *Pristomopoides filamemtosus*, *P. typus* and *P. multidens*). These fisheries are particularly important to small island states that often have few other demersal fish resources though they are also widely found along the continental margins of many continents in tropical and sub-tropical areas.

LIFE-HISTORY CHARACTERISTICS OF DEEPWATER FISH

Not surprisingly, given the characteristics of their habitat, colouration, jaw structure, musculature, fin and swimbladder form and eyes are characteristically modified in deepwater fishes. In the absence of light most deep-sea fish are black or red as this wave length is highly attenuated in seawater and such fish effectively have black colour. Despite the lack of light, deepwater fish often have large eyes and unusual retinal and lens adaptations to detect the ambient light, which usually arises from photophores on prey, predators or co-specifics. Many deepwater species have reduced muscle and bone mass, which gives them near neutral buoyancy: those that prey by slowly cruising have swimbladders capable of excreting gas despite the ambient hydrostatic pressures of about 400 atmospheres present at great depths (Marshall 1954, 1979).

Deepwater species too, must successfully spawn, grow and return to the area of the adult habitat. The extreme conditions of the deep-sea are reflected in the variety of reproductive strategies that exist. Low population sizes not withstanding, hermaphroditism, extreme sexual dimorphism and unbalanced sex ratios occur. Despite the fewer species found in the deep-seas, they display a variety of reproductive strategies ranging from strongly *K*-selected species, which may be semelparous (e.g. *Coryphaenoides armatus*, a widely occurring macrourid), through ovoviparous and oviparous species to those that are strongly *r*-selected. It is believed that successful year classes may be intermittent, and many deepwater species may spawn only periodically over the years.

A number of tactics have been adopted to reduce dispersion of eggs. The buoyant eggs of the wide spread and deepwater macrourids bear sculptured patterns that slow their ascent, an adaptation not present in species of this family living in shallower waters. Eggs of *Hoplostethus atlanticus* are initially buoyant and later sink and probably finish their development on the seafloor, so facilitating their retention to their adult habitat.

PRODUCTIVITY

A major determinant of fishery productivity is the growth rate of the fish and invariably, the size distributions of fish populations that are usually negatively skewed. However, bimodal size distributions have been found for some deepwater species and one explanation for this is that because of their unproductive habitat, deepwater species are obliged to put their surplus production into somatic growth to achieve an optimal foraging size and only then do they allocate surplus energy to reproduction.

No matter the reason, it is clear that many deepwater species grow slowly, so slowly in fact that determination of their actual age remains difficult and age determination has been contentious. For some species, particularly orange roughy (*Hoplostethus atlanticus*), the appropriate ageing technique has been vigourously contested, and depending on the assumptions that were asserted, the species could have had a potential longevity ranging from 21 to >100 years; current thinking now accepts the hypothesis that these fish grow to relatively old ages, with the maximium > 100 years.

Many deep-sea fisheries biologist have concluded that it is not meaningful to talk about deepwater fisheries in terms of sustainable fisheries, so slow are the growth rates of many of these species, a characteristic that is compounded by their apparently episodic recruitment. In such fisheries if the resource consisted of widely-separated age-classes that are fished to very low levels of abundance, stock recovery arising from good recruitment may only be possible in generation terms greater that those of humans.

DEEP-SEA FISHERIES

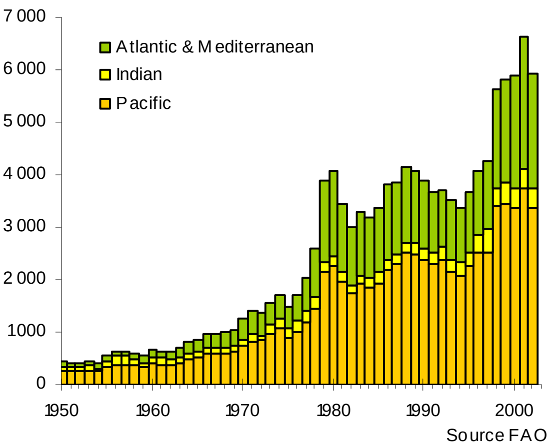
Until most recently, the great depth of the deep-sea has made it difficult to exploit, and the existence of relatively more abundant resources in shallower seas have meant that there was little incentive to fish in such difficult-to-exploit regions. Few deepwater fisheries are of long standing and those that are the Portuguese (Madeira) line fishery for black scabbardfish (*Aphanopus carbo*) and Pacific Island fisheries for snake mackerels (Gempylidae) and cutlass fish (Trichiuridae) were initially exploited by artisanal fisheries whose effects upon the resources were sustainable.

Well known among recently developed deepwater fisheries is that of the orange roughy, a species that inhabits slope waters, those of seamounts and the seafloor, most notably around New Zealand and Southeast Australia where this commercial fishery initially began; interestingly, orange roughy was first described from the Azores. The fishery later spread to the Walvis Ridge in the Southeast Atlantic (Namibia), the Southwest Indian Ocean and a small fishery exists in the Bay of Biscay. This long-lived fish reaches about 40 cm and 2 kg in size though the maximum size varies with region. Specialized aimed-trawling techniques have developed as at first massive catches from spawning aggregations could be taken in minutes resulting in split cod ends and lost catches. The species is sensitive to approaching objects (an adaptation to avoid predation by sperm whales?) so that acoustic assessment using towed bodies containing the acoustic transducer has proved difficult in some areas. Maximum sustainable levels of exploitation of orange roughy may be as low as 5-10 percent of unfished biomass, i.e. M ~ 0.04. Accumulating evidence indicates that few of these fisheries are being exploited sustainably and it remains uncertain what ongoing yields will be. Smaller stocks usually do not escape depletion once they become targetted, however, there is conflicting evidence that other stocks have proven more resilient to overexploitatin that expected, possible because (a) fishing disperses the fish before the stock is fished down and, (b) because of episodic spawning. In this case, where fishing depends on spawing aggregations not all of the stock may be vulnerable to capture in any one year as not all spawn each year (Butterworth and Brandão 2005).

A Trichiurid fishery, which exploits *Aphanopus carbo*, is a rare example of a deepwater fishery that, because it has traditionally used hook and line gear, has proved sustainable over a period of about 150 years. Adults of this species are benthopelagic living in the deep range 400-1 600 m. The species ranges from Greenland to the Canary Islands and on both sides of the mid-Atlantic ridge. This deepwater species grows rapidly and has longevity of around 8 years. However, as for orange roughy, the usual ominous signs are now evident for this fishery. Catch increased from 1 100t in 1980 to 3 000t in 1992 and gear efficiency has increased through the introduction of monofilament lines and a large increase in the number of hooks per line set, now 4 000–5 000 per line.

The Macroudidae are another group whose members are widespread and in particular locations, abundant. They are typical pelagic “cruisers” and inhabit the mid- to upper region of the continental slope. In the North Atlantic fisheries exist for *Macrourus berglax* and *Coryphaenoides rupestris*, which use bottom trawls initially fishing in depths of 600–800 m, and more recently to 1 500 m. However, experience in these fisheries off Newfoundland

Figure C3.8 - Annual nominal catches ('000t) of Deepsea species



shows the all-too-familiar pattern of total allowable catches tracking declining trends in reported landings. *Coryphaenoides rupestris* have a potential longevity of 70 years, through in the NE Atlantic, fish ages are usually of 20–30 years. Thus, as for other deepwater species, Macrourids exhibit the characteristics of many deepwater fisheries that render them particularly susceptible to overfishing.

The Pleuronectidae are a highly evolved group that are not usually associated with deepwater fisheries, but important fisheries for members of this group occur in both the North Atlantic and North Pacific Oceans. In the Atlantic, the best known has been that for Greenland Halibut (*Reinhardtius hippoglosoides)* on the continental slope depths. This fish had an average size of around 1kg up until the mid-1980s, but has since declined to around 200g in the early 1990s.

Figure C3.8 represents the evolutioncaptures of the deep-sea species listed in table C3.1. Some of these species however can also be captured in other fisheries and there is no possiblility to determine which portion comes from deep-sea fishing. These statistics only reflect the amount of deep-sea species catches reported to FAO by member countries. No information is available to attribute the changes in 1979 and 1998 to an increase of actual catches or a better reporting.

RESOURCE MANAGEMENT ISSUES

The biological features of deepwater species that may be caught by the same fisheries are varied and require that appropriate management strategies are adapted. Different species complexes may occur in the same general area but at different depths. For example, in the southern Indian Ocean fisheries characteristically at depths of 800 m commonly target orange roughy (*Hoplostethus atlanticus*), black oreo (*Allocyttus niger*), spiky oreo (*Neocyttus rhomboidalis*) and smooth oreo (*Pseudocyttus maculatus*). When fishing at depths of ≈400 m, these vessels would commonly harvest alfonsino (*Beryx splendens*), boarfish (*Pseudopentaceros richardsoni*), cardinalfish (*Epigonus telescopus*) and bluenose (*Hyperoglyphe antartica*).

Such fisheries may have little bycatch (and thus discards), i.e. the fisheries could be considered “clean” in that few non-targeted species are taken. However, unskilled operators, who snag the bottom, can cause significant damage to the benthos. And, lost catch from burst codends results in fishing mortality that is rarely recorded.

In these fisheries, traditional tools of fisheries management, e.g. those that assume annual recruitment and a functional stock-recruitment relationships may fail so badly that using them may endanger ensuring sustainability of the resources, rather than conserving them. Although characteristically deepwater resources are harvested by trawling, from a management perspective, the fishing tactics have more in common with purse seining. Fishing may be done on acoustic marks, especially in the case of orange roughy fisheries or by extended tows as when targeting alfonsino.

When fishing for orange roughy catch success critically depends on crew skills and the success of fishing tactics rather than, e.g., the dimensions of the fishing vessel. In recording fishing effort, the main requirement is to know if the net was a bottom or pelagic trawl, and in the latter case, if it was fished “hard-down” and if the gear performed as intended, i.e. was the tow “successful” even if no fish were caught. Related to this are fishing tactics in the presence of other vessels. Vessels with crews with inferior skills often trailed better performing vessels relying on them to locate concentrations of fish. In these cases, complex gaming behaviour on the part of the skipper could result further complicating interpretation of vessel operating success. While catch per unit effort (CPUE) remains one of the most useful indices of stock status, as noted, in these vulnerable fisheries, its undue emphasis it could well be misleading, if not dangerous.

A further complication of deepwater research, especially on the high seas, is the provision of data that are essential for resource management

Table C3.1 Species of deepwater fish recorded in the FAO Reported Landings Database

Crustaceans	ARISTAEIDAE	*Plesiopenaeus edwardsianus*	Scarlet shrimp
	GERYONIDAE	*Geryon quinquedens*	Red crab
	LITHODIDAE	*Lithodes aequispina* *Paralomis spinosissima*	Golden king crab Antarctic stone crab
	PANDALIDAE	*Pandalus spp*	Pandalus shrimps
	SOLENOCERIDAE	*Pleoticus robustus*	Royal red shrimp
Chondricthyans	CALLORHINCHIDAE	*Callorhinchus capensis* *Callorhinchus milii* *Callorhinchus spp*	Cape elephantfish Ghost shark Elephantfishes
	Chimaeras, etc.	*Chimaeriformes*	Chimaeras, etc.
	CHIMAERIDAE	*Chimaera monstrosa* *Hydrolagus novaezealandiae* *Hydrolagus spp*	Rabbit fish Dark ghost shark Ratfishes
	HEXANCHIDAE	*Hexanchus griseus*	Bluntnose sixgill shark
	RAJIDAE	*Bathyraja meridionalis* *Bathyraja spp*	Bathyraja meridionalis Bathyraja rays
	SQUALIDAE	*Centroscymnus coelolepis* *Centroscymnus crepidater* *Somniosus microcephalus* *Somniosus pacificus*	Portuguese dogfish Longnose velvet dogfish Greenland shark Pacific sleeper shark
Teleosteans	ARGENTINIDAE	*Glossanodon semifasciatus*	Deep-sea smelt
	BERYCIDAE	*Beryx spp* *Centroberyx affinis*	Alfonsinos Redfish
	BRANCHIOSTEGIDAE	*Branchiostegidae*	Tilefishes
	CAPROIDAE	*Caproidae*	Boarfishes
	CENTROLOPHIDAE	*Hyperoglyphe antarctica* *Seriolella caerulea*	Bluenose warehou White warehou
	CHLOROPHTHALMIDAE	*Chlorophthalmidae*	Greeneyes
	EMMELICHTHYIDAE	*Emmelichthyidae* *Emmelichthys nitidus*	Bonnetmouths, rubyfishes Cape bonnetmouth
	EPIGONIDAE	*Epigonus spp*	Cardinal fishes
	GADIDAE	*Brosme brosme* *Micromesistius australis* *Micromesistius poutassou* *Molva dypterygia* *Molva molva*	Cusk Southern blue whiting Blue whiting Blue ling Ling
	GEMPYLIDAE	*Lepidocybium flavobrunneum* *Rexea solandri* *Ruvettus pretiosus* *Thyrsitops lepidopoides*	Escolar Silver gemfish Oilfish White snake mackerel
	GERYONIDAE	*Geryon spp*	Geryons
	MACRORAMPHOSIDAE	*Macroramphosus scolopax*	Longspine snipefish
	MACROURIDAE	*Coryphaenoides rupestris* *Lepidorhynchus denticulatus* *Macrouridae* *Macrourus berglax* *Macrourus spp*	Roundnose grenadier Thorntooth grenadier Grenadiers, rattails Roughhead grenadier Grenadiers
	MERLUCCIIDAE	*Macruronus magellanicus* *Macruronus novaezelandiae* *Macruronus spp*	Patagonian grenadier Blue grenadier Blue grenadiers
	MORIDAE	*Antimora rostrata* *Mora moro*	Blue antimora Common mora
	MYCTOPHIDAE	*Lampanyctodes hectoris* *Myctophidae*	Hector's lanternfish Lanternfishes
	NOTOTHENIIDAE	*Dissostichus eleginoides* *Dissostichus mawsoni*	Patagonian toothfish Antarctic toothfish
	OPHIDIIDAE	*Genypterus blacodes* *Genypterus capensis* *Genypterus chilensis* *Genypterus maculatus* *Genypterus spp*	Pink cusk-eel Kingklip Red cusk-eel Black cusk-eel Cusk-eels
	OREOSOMATIDAE	*Oreosomatidae*	Oreo dories
	PENTACEROTIDAE	*Pseudopentaceros richardsoni*	Pelagic armourhead
	PLEURONECTIDAE	*Reinhardtius hippoglossoides*	Greenland halibut
	POLYPRIONIDAE	*Polyprion americanus* *Polyprion oxygeneios*	Wreckfish Hapuku wreckfish
	SCORPAENIDAE	*Scorpaena scrofa*	Red scorpionfish
	STERNOPTYCHIDAE	*Maurolicus muelleri*	Silvery lightfish
	SYNODONTIDAE	*Harpadon nehereus*	Bombay-duck
	TRACHICHTHYIDAE	*Hoplostethus atlanticus* *Trachichthyidae*	Orange roughy Slimeheads
	TRICHIURIDAE	*Aphanopus carbo* *Lepidopus caudatus* *Trichiuridae* *Trichiurus lepturus*	Black scabbardfish Silver scabbardfish Hairtails, scabbardfishes Largehead hairtail
	TRIGLIDAE	*Pterygotrigla picta*	Spotted gurnard

FAO 2001, 2002). The operators of many high seas fishing vessels have no flag-responsibility to report their catches, fishing effort or area of operations. And, when catches are landed in foreign countries, from a data recording perspective, this situation is exacerbated. An example of such a fishery is that of the North Pacific pelagic armourhead (*Pseudopentacerus wheeleri*). No trace of this fishery is to be found in the FAO *Nominal Catches and Landings Database*, the largest and most comprehensive global record of fish catches, despite this fishery being reported as reaching a level or 200 000t per year! Likewise, the FAO database in the period up to 2000 reports explicit landing of orange roughy from only three countries; however, informal contacts through working groups shows that at least seven countries have harvested this species from the Indian Ocean. In some cases this lack of information is a consequence of national laws regarding confidentiality of information. Characteristically only few vessels, or even one, may participate in seamount-based fisheries within a management region, which if stock-based may consist of a single seamount. And, national laws often prevent governments from releasing information that identifies the operations of a single vessel or company. This can create an insurmountable barrier to effective resource management.

MANAGEMENT OBJECTIVES: IS "SUSTAINABLE YIELD" A PRACTICAL GOAL?

Management for sustainable yields, as a management objective, has been increasingly criticized in "conventional" fisheries for nearly two decades as numerous fishery administrations have struggled to implement such a management paradigm. As a consequence, the management emphasis has changed towards the use of reference points as simpler, more tractable and more useful tools. In a complementary and more complex development is the emerging demand for "ecosystem" management. When considering the circumstances of many deep-sea fishes, it is clear that major challenges arise in adapting such models, if indeed they can be adapted to deep-sea fishery situations. First, "sustainability" may be an irrelevant or at least unusable management concept in fisheries where the resources have episodic and unpredictable recruitment, no matter the spawning stock size. Second, for those species with low growth rates and late sexual maturity, use of conventional limit spawning biomass reference levels, few stocks may remain which can satisfy these demands and should they do so, harvest rates may have to be in the order of five percent of virgin biomass. Third, stock recovery times may be of the order of decades, perhaps beyond normal commercial (and political) time horizons. Fourth, even if there were agreement on management objectives and harvest control functions, in many instances neither the management regimes nor regulatory mechanisms exist to ensure compliance with any management plan. These are the challenges that must be addressed if the world's deepwater resources are not to disappear as contributors to human welfare.

OPERATIONAL MANAGEMENT: THE ASSESSING AND MANAGING OF EXPLOITATION OF DEEPWATER FISHERIES

This section is drawn from the report of the FAO Workshop on the Assessment and Management of Deepwater Fisheries, University of Otago, Dunedin, New Zealand, 27–29 November 2003 (FAO 2005)

The estimation of abundance

The estimation of the abundance of deepwater fishery resources has many of the characteristics of those for more traditional shelf stocks but other attributes are unique to deepwater species. Some deepwater species, such as orange roughy, have low productivity, are highly aggregating, are often, but not exclusively, found around underwater features, and that they react to survey and fishing gear not just at the time of capture but also over longer periods. The reasons for aggregating behaviour (e.g. suitable conditions or learned behaviour) remain uncertain and more research on fish behaviour is highly desirable. However, the low productivity in deepwater may not be universal. Some "deepwater" species (particularly those with long pelagic phases, strong diurnal migration patterns, or preferred depths above about 800 m) have moderate levels of productivity.

Egg surveys, methods often used for shallow water stocks, may peform poorly in estimating abundance for a variety of reasons, among which are the highly localized spawning behaviour (e.g. orange roughy) of some species while others (e.g. some oreos and boar fish) may have wide-region panmictic spawning behaviour. Trawl and acoustic surveys are potentially the most useful methods for estimating abundance and both can be used to obtain relative abundance indices, although the use of acoustics is difficult even for relative abundance estimation when the target species is also associated with other species during the survey period. Both methods present problems with respect to the estimation of absolute abundance. For acoustics assessment, difficulties include identification of the values of species-specific backscattering cross section areas and target species identification. For trawl surveys, estimating the vulnerability to capture (i.e. survey catchability) is problematic.

The use of remotely operated vehicles and autonomous underwater vehicles has potential for use in abundance estimation, or in experiments to estimate vulnerability to capture by trawls but further development is needed. But, methods based on developments in technology will require advances in the understanding of fish behaviour (natural and in response to fishing and research vessels and gear). In particular, further work is needed on factors influencing aggregating behaviour and such underwater technology may offer opportunities in this respect.

Additional issues concern those relating to identifying stock structure, stock distribution and movement. Obtaining some form of relative or absolute abundance estimates may be feasible, but their validity will depend on appropriate survey designs that take account of underlying distributions and movements. As yet, it appears that there is no single best way to estimate abundance and that use of a range of methods will offer the best way forward. In some areas, trawl and acoustic surveys are in regular use and the estimates and indices derived are used in stock assessments with varying degrees of success, but this often depends on the availability and quality of other data sources.

The costs of deepwater fishery resource surveys is high and commonly the cost-benefit of surveys is a consideration in deciding on best ways forward in any particular circumstance. Dedicated research cruises provide the best means of providing abundance estimates, and can often undertake a wider range of associated work at the same time. However, the use of industry-based surveys (especially acoustic surveys) is providing useful inputs for stock assessments and considerable advances are being made in this direction.

Biology, age and growth

Management of deepwater species is complicated by the wide variability in their biological characteristics. Many species have high longevity, slow growth rates, high age at maturity and low fecundity and many, but not all, deepwater species have relatively low annual production to biomass ratios. For such stocks, this means that sustainable yield levels are relatively low, and recovery from depleted states can be slow.

Routine data collection and analysis is essential for effective management and should not be restricted to the needs for immediate stock assessment purposes. Biological characteristics (e.g. size-at-maturity) can change as fish stock size changes so such characteristics need to be monitored as ancillary inputs to evaluating stock status. Density dependent effects need to be considered in the stock assessment, as estimates of catchability, maturity, growth rates, spawning success and other factors may change. Stock structures of most deepwater species are generally poorly known and their depth means that direct methods to monitor distribution and movements (such as by tagging) can rarely be applied.

Fish population parameters are often poorly known, and variable. And complicating the use of spawning models is that several deepwater species (e.g. orange roughy and hoki) do not spawn each year. This means that reliance upon gonad stage data to determine age at maturity, or the maturity ogive, may be misleading. In the case of orange roughy, there is a transition zone in the otolith that appears to mark the onset of spawning. However, the frequency of spawning is important, in terms of the proportion of the population available to the fishery or the biomass survey each year, particularly if the proportion varies between years. Stock-recruitment relationships, and levels of recruitment, are poorly known for most, if not all, deepwater species. Yet this is important for understanding changes in stock size, and for the management of sustainable fisheries.

Chemical and radiometric methods have improved confidence in the interpretation of otolith rings of deepwater species and improved age-method validation. In the absence of initial data, general age and growth estimates may be available from other areas or fisheries. Ageing for production estimation is still needed, however, in the major fisheries.

There is a pressing need to try to understand the ecological processes affecting biological variability for without this, predictive modelling can be misleading. At the least, consideration should be given to trophic interactions and links between deepwater demersal fish and the mesopelagic energy source.

Assessment of eepsea fisheries

A number of key data gaps and data needs exist for reliable assessments of deepwater species. Three, in order of priority are:

- Catch data at the minimum, it is essential to know the amount and location of fisheries catches. This needs to be collected at an appropriate spatial scale given the localized aggregations formed by many deepwater species. It would also be useful to collect data on length frequency distributions of target species, and catches of by-catch species.

- Valid indices of relative abundance–preferably, these should be fishery-independent but, realistically, they are likely to be fishery-dependent commercial catch rates. It is extremely difficult to develop "valid" interpretations of the indices at the beginning of a fishery; however, programmes should be developed to collect data on relevant factors such as the relationship between commercial CPUE and abundance, selectivity by fisheries, stock boundaries, migration patterns, and the dynamics of aggregating behaviour.

- Estimates of absolute abundance–ultimately, these are needed to estimate long-term sustainable yields. They can be obtained either from a fishery-independent survey that provides estimates of absolute abundance (e.g., an acoustic survey) or an assessment model that estimates absolute abundance based on catch and relative abundance.

Other data needs that may be crucial for some stocks, and will almost always improve the accuracy and precision of assessments if available, include:

- relative or absolute estimates of recruitment;
- the relationship between stock size and recruitment; and
- age data.

Although age information is essential for estimating population productivity, it is less important to devote resources to ageing stocks for which age and growth information already exists for other stocks of the same species. Knowledge of fish ages (which enables estimation of growth rates, natural mortality, and sometimes recruitment) was crucial for determining sustainable yields for orange roughy fisheries when they were first initiated. But, it was not until a validated ageing system was developed that it became evident that orange roughy had unusually low growth rates, low natural mortality, high age at maturity and high longevity. Ageing of other orange roughy populations has demonstrated some differences in these life history parameters, but such differences may be insufficient to justify initiation of major research initiatives on ageing, particularly if resources are limited. It may be better to give higher priority to other data needs, such as the need for abundance indices, and simply adopt the age-length keys, growth parameters and natural mortality estimates from other similar stocks.

Finally, to satisfy objectives that are often mandated by international agreements or national policy, it may be necessary to augment existing, or to set up new, programmes to provide data on ecosystem considerations, such as bycatch species, other associated species, and the effects of fishing on habitat. In multi-species fisheries for which it is extremely difficult to obtain species-specific data on catch and abundance, these may need to be assessed and managed as species assemblages, with application of the precautionary approach with regards to setting catch or effort limits.

Management concerns of deep-sea fisheries

Biological reference points

Options for reference points include frameworks based on control rules using target and limit reference points and management procedures that consider the assessment and management systems in concert using various performance measures to evaluate outcomes. In general, the use of evaluation approaches to derive robust management procedures is desirable; however, in the case of many information poor fisheries the feasibility of doing this is questionable. For many low-productivity stocks, target biomass levels used for management purposes vary from about 30 percent to 55 percent or higher of the unexploited level and rather than setting targets, a more useful approach may be to concentrate on avoiding a lower biomass (typically 20 percent of unexploited) with a high probability (typically 90 percent). Depending on the uncertainty inherent in any assessment and projection, the implied target biomass would vary but would likely fall within the range of typically adopted targets. In this regard though, some scientists consider fishing mortality reference points to be a superior approach.

Ecosystem approach to fisheries management

Even in deepwater fisheries, the single most important first step in moving towards an ecosystem approach to fisheries management is to get single-species fishing mortality under control and reduce it to appropriate levels. For this to happen, assessment and management of marine resources must be better integrated with appropriate management frameworks that ensure single stock management is successful while considering wider environmental or ecosystem issues.

Data-poor situations

In many deepwater fishery situations, there may be little or no information available to set initial catches, assess stock status or estimate reference points. Adaptive management may be useful but there is often tension between adaptive management procedures that probe for information (and therefore require that catches be high enough (or low enough) to create contrast in data sets) and the adoption of a precautionary approach, which would suggest low catches for low productivity stocks. Evaluated (adaptive) management procedures may also be problematic if the information that is accrued shows that the assumptions used in management and resource modelling are untenable and must be re-evaluated. In these situations meta-analyses may provide a means of garnering the maximum possible benefit from the dispersed global data on deepwater stocks, fisheries and associated habitats. Such an analysis could provide a means for setting initial catch limits for new fisheries as a basis for adaptive and/or precautionary management.

Precautionary approach

The approach of treading carefully and restricting catches in early phases of deepwater fisheries is well supported. In New Zealand, new orange roughy fisheries are voluntarily capped at 500 t while information is gathered. The Commission for Conservation of Antarctic Marine Living Resources (CCAMLR) does not allow new fisheries unless they are explicitly allowed and involve permit conditions such as mandatory data collection procedures. Although there is growing support for such approaches, still, rapid declines in biomass of low productivity stocks occurs as the initial biomasses of the resources have, almost invariably, been overestimated.

ECOSYSTEM CONSIDERATIONS OF THE DEEP-SEA ENVIRONMENT

Given its great depth, extent and, until only the most recent years, its low to non-existent visible profile, it is unsurprising that the environment of the deep-sea has escaped concern. But, much evidence now shows that human activity is degrading the deep-sea floor and along with it the habitat of the fish that live there. Major causes of this damage the physical impact by trawls on benthos (Koslow *et al.* 2000) and ocean dumping of sludge residuals from the processing of sewerage; of growing concern is petroleum exploration activities, and potentially in the future, mineral extraction.

Deep-sea surveys have shown the existence of deepwater corals in the North Atlantic, North Pacific, south of Australia, about New Zealand and almost certainly they will occur elsewhere. In the North Atlantic, the dominant genus *Lophelia* occurs in depths between 200-1 000 m and grows at a rate of about 1 mm per year. The highest reefs have measured 35 m, implying an age of 8500 years and the largest Lophelia reef are more than 13 km long and reach 400 m in width. Off Nova Scotia, corals are found far from shore in depths > 200 m. Here, species known to exist include *Paragorgia arborea* (Gorgonacea), which can be up to five metres in height and *Primnoa resedaeformis* (Paragorgia), which, fishermen report, grows in dense patches where is has not been removed by demersal trawling.

Such reefs provide shelter for marine fishes, which in the NE Atlantic include commercial species such as redfish, saithe, cod, ling and tusk. The reefs have traditionally been rich fishing grounds for longline and gillnet fisheries and experimental fishing has shown the occurrence of productive fishing grounds in relation with the presence of bottom corals. Evidence is emerging that the maintenance of bottom habitat corals structure is important to maintaining fish production and at least in shallower waters, habitat degradation by bottom trawling can result in fish species succession, perversely, for types that are of least commercial value.

Deepwater corals are sensitive to damage from bottom trawls, e.g. in Norwegian waters it is estimated that 30-50 percent of the Lophelia reefs have been affected or impacted by trawling. Damage has also been reported from other parts of NW Atlantic, including northwest of Scotland and in the Porcupine sea bight in Irish waters and off the coast of Nova Scotia where active clearing of bottom corals has been reported. In Australia and New Zealand it is claimed that fisheries using demersal trawls have cleared corals from the rocky tops of seamounts and fish that were once abundant among the corals have disappeared.

Seamounts provide another particular fish habitat of concern. These seafloor features are usually found in the open oceans and are the remains of extinct volcanoes. They range from 500 to 1000 m in height above the seafloor; some reach within tens of metres of the surface while others have tops more than a kilometre deep. The associated fauna with seamounts is poorly studied and highly diverse and can include corals, soft sea pens, sponges, sea spiders and lobsters. Many of the species are endemic to particular sea mounts as they form isolated habitats. Once damaged by fishing gear, it is believed that recovery may take decades, if not centuries.

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