PART 2: EXPERT CONSULTATION BACKGROUND DOCUMENTS

DEEP-SEA RESOURCES AND FISHERIES[1]

by

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1. INTRODUCTION

This paper was commissioned as an overview document to be presented at the Expert Consultation on Deep-Sea Fisheries in the High Seas organized by the Food and Agricultural Organization of the United Nations in November 2006. This expert consultation is a follow-up to Deep Sea 2003, a conference dedicated to deep-sea fisheries and related issue held in Queenstown, New Zealand in December 2003. At this conference there was also a strong desire expressed by some scientists, non-governmental organizations (NGOs) and seafood industry representatives to work with governments and other agencies on solutions to the management of deep-sea ecosystems and "to contribute constructively towards the development of long term management frameworks within which legitimate fisheries could continue" (Shotton, 2003).

This paper aims to provide a broad overview of global deep-sea fisheries, informing decision-makers, fishery managers, administrators, NGOs and other interested and affected parties. As far as possible, the text does not include detailed taxonomic nomenclature and scientific terminology and should therefore give readers an uncomplicated perspective on deep-sea fisheries and related issues. It is also stressed that a review of the literature and data available on deep-sea fisheries presents an enormous amount of information. Many authors have quite different points of view regarding the deep sea including artisanal line fisheries (in which deep would be interpreted to be 400 metres [m]) and large industrial trawling in which deep sea has a quite different interpretation. This overview therefore provides an opinion on different aspects of deep-sea fisheries and aims at stimulating discussion around the major issues.

2. DEFINING "DEEP SEA"?

No clear definition(s) exists for "deep sea". In the context of this review the author focused on a definition used by FAO[3] consisting of regions off the shelf and deeper than 200 m. In a broad sense, the deep sea can be defined as the area (Figure 1) from the near shore >200 m water depth to the shelf edge (approximating the 500 m depth contour) and extending beyond the shelf to include the slope, or depths that technology presently permits trawling (about 1 500 m water depth). Depths fished by other gears (demersal longlines and traps for example) may extend this range somewhat by a further 1 000 m or as deep as 2 500 m.

In the context of this review, deep sea refers primarily to demersal resources, or marine fauna found on or near the sea bed (benthic and benthopelagic). The emphasis is on marine fish in the taxonomic

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[1] This document was prepared for the Expert Consultation on Deep-sea Fisheries in the High Seas which took place in Bangkok, Thailand from 21 to 23 November 2006.

[2] The views expressed in this paper are solely those of the authors, Dave W. Japp, P.O. Box 50035, Waterfront, Cape Town, 8002, E-mail: jappy@iafrica.com, and S. Wilkinson.

[3] Please note that this is not the official FAO definition, but has been used in other FAO documents. (FAO. Report on DEEP SEA 2003, an International Conference on Governance and Management of Deep-sea Fisheries. Queenstown, New Zealand 1–5 December 2003. *FAO Fisheries Report*. No. 772. Rome, FAO. 2005. 84p.)

Class Pisces including the cartilaginous fish (Chondrichthyes) and bony fishes (Osteichthyes). Further, the exploited resources reviewed include meso-pelagic fish (mostly caught off the bottom, but generally in deeper than 200 m water depth) but not the highly migratory stocks of tunas, billfishes and shark (pelagic stocks – Figure 1). Crustaceans are also impacted by deep-sea exploitation but are not discussed in any detail in this paper.

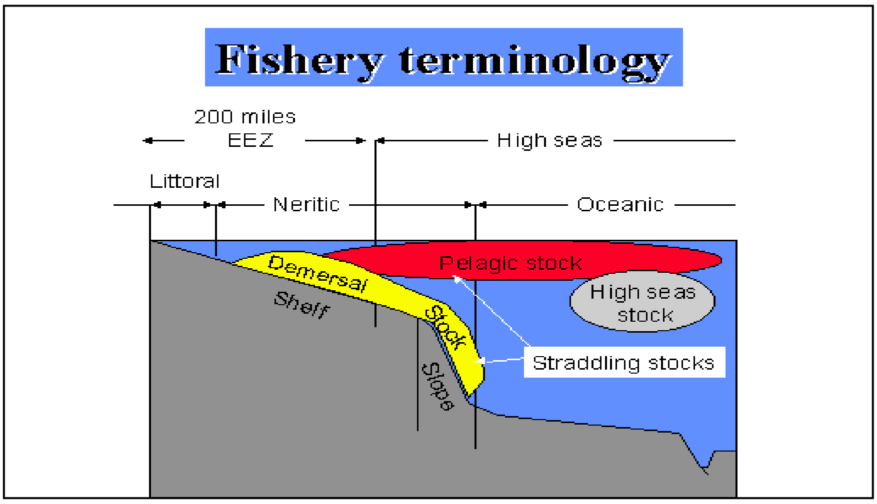

Figure 1. Fishery terminology used to define deep sea.

In some instances deep sea has also been defined as extending to the known depth limits of the oceans in which deep-sea trenches, hydrothermal vents and seamounts are considerations. Although these areas are of academic interest (e.g. biodiversity, geology and plate tectonics, biochemical, etc.) they are, with the exception of many seamounts, not presently impacted directly by fishing.

It should also be kept in mind that our perception of what is actually deep has changed over time. Historically, offshore trawling described activity on the shelf, generally not exceeding 500 m water depth. The abundance of target species such as the gadoids (e.g. cods and hakes) did not necessitate fishing beyond this depth. The distinction between the directed effort on the shelf and that off the shelf was always clear. The deepwater exploratory operations of the large Russian freezer trawlers in international waters in the 1950s and 1970s was, for example, distinctly different from the coastal-based trawling that developed on the continental shelves and remaining within economically viable distances from home ports. The target areas of these high seas fleets were the oceanic ridges (annex 1, Figures 12-14) and seamounts where species such as alfonsino (*Beryx* sp.) and orange roughy (*Hoplostethus atlanticus*) were often caught in large quantities.

The main point here is that in the last two decades there has been a systematic increase in the depths fished by coastal offshore fisheries, effectively merging shelf fishing with the deep sea. The primary reason for this is obviously the depletion of once abundant shelf resources and the subsequent gradual shift in fishing effort to deeper water off the shelf and onto continental slopes in search of better catches. Although deep-sea species might not have been intentionally targeted, it certainly resulted in increased landings of a new spectrum of species that could be defined as deep sea bycatch. The extent of the deep-sea areas between 200–2 000 m is illustrated in Annex 1 as well as the trends in deep-sea catches in each ocean region are elaborated on later in Figures 12-14 (Annex 1). The location of seamounts and their proximity to the continental shelves, as illustrated by Stocks and Boehlert (2003) in their international census of marine life also provides a useful perspective.[4]

[4] There was much debate on the definition of "deep-sea" at the expert consultation. The following captures the salient points defining "deep-sea" emanating from the discussions: "Deep Sea Fisheries are fisheries that mostly target resources found at the edge of the continental shelves extending into deeper water down the slopes. The areas in which these fisheries occur include seamounts and oceanic ridges found predominantly (but not exclusively) on the high seas. In most instances (but not

Gordon (2003) also pointed out the differences between continental slopes, seamounts and ocean ridges and gives an excellent description of the differences in the physical environments between these areas. Gordon (2003) also notes that the physical area considered here as deep sea (200–2 000 m) comprises only 8.8 percent of the total ocean area in the world. Contributing to this "merging" of the deep-sea domains was undoubtedly the considerable advances in technology and vessel capacity that facilitated the systematic extension of the coastal fleets into deeper water (but was not the primary reason for moving into deeper water). In doing so a new species assemblage has been impacted, quite different from those target species and bycatch traditionally exploited on the continental shelves.[5]

3. IT'S ALL RELATIVE – THE HISTORICAL DEVELOPMENT OF DEEP-SEA FISHERIES

Successful exploitation of the deep sea in this author's view relates to a combination of three main factors:

- resource availability/abundance;
- technology and information; and
- economics (costs and benefits).

Prior, even to Columbus landing in North America, Spanish (basque) fishers targeted cod (with lines and longlines) from boats sailed from Spain across the North Atlantic to the Grand Banks returning with salted cod. What made this fishery viable was the use of salt to preserve their catch. This was a simple technological advancement that at the time was not known amongst fishers in other parts of the world. Gear constraints and depths fished were not major limitations as cod availability was high, so that there was no need to fish "deep". Given the time and risks involved, the trade off with the value of the catch was quite remarkable. Simply speaking, all three conditions for a viable deep-sea fishery had been fulfilled.

By comparison, the use of steel trawlers (steam driven) started in the late 19th century and resulted in the rapid advancement of offshore fishing. Despite the evolution of modern-day trawling, bigger and more robust sea-going vessels, etc. in the early part of the 20th century, effort remained relatively close inshore. Technology was not critical as resource abundance inshore was high. For example, hake-directed effort off the Agulhas Bank (Japp *et al*. 1994) in the first half of the 20th century was sustained in relatively shallow water (< 100 m). The South African hake fishery has systematically moved into deeper water and the most recent trend is to target deepwater hake at depths exceeding 600 m resulting in a distinctly different bycatch (deepwater) component.

From 1953, fishers in Russia began fishing deep, targeting rock fish (*Sebastes* sp.) and Atlantic halibut (*Hippoglossus hippoglossus*) off the continental shelf (on the slopes) in the Barents Sea (Lapshin and Korotov, 2003). These fishers are considered by some to be the "pioneers" of deepwater fishing in Russia and were the forerunners of the operations of the large bottom and midwater exploratory freezer trawlers that started in 1967 targeting roundnose (rock) grenadier (*Coryphaenoides rupestris*) and black halibut (*Reinhardtius hippoglossoides*) at depths up to 1 000–1 100 m in the North Atlantic. Simultaneously deepwater fishing (on the slopes of the continental shelf) for sablefish (*Anoplopoma fimbriata*) was started in the Pacific Ocean by the Russian high seas (industrial) fleets. The Atlantic fleet (Russian) vessels also systematically moved south along the Mid-

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exclusively) these fisheries target stocks and species not found on continental shelves and which generally have low productivity. The depths at which these resources are found are centred below 200 m and occur mostly from 400 m into deeper water and impact unique ecosystems that include coldwater corals and other fauna".

[5] It should be noted that the exploitation of these new species assemblages are not necessarily target species. For example, the shift of effort into deeper water (> 600 m) off the South African coast in recent years (since 2003) was primarily to target larger deepwater hake Merluccius paradoxus due to reduced catch rates in the shallower shelf areas (350 – 550 m water depth). This resulted in a significantly different (incidental) bycatch component i.e. deepwater species.

Atlantic Ridge conducting exploratory fishing around the Azores and Walvis Ridge (Japp, 2003). Data from these exploratory cruises reflect high levels of detail when describing grounds and species targeted (Anon, 1996).

Some of these vessels have, until recently, still been active in the South East Atlantic targeting hake and horse mackerel in the Benguela region under the jointly managed International Commission for South East Atlantic Fisheries (ICSEAF, disbanded in 1990 at the time of Namibian independence). Up to 2004, some of these vessels were still fishing horse mackerel in Namibian (Japp, 1996) and South African waters and were also used when the deep sea South West Indian Ocean fishery developed (Japp, 2004). Uncertainty relating to the historical catches of not only hake in the Benguela region, but also unknown quantities of orange roughy (*Hoplostethus atlanticus*) in the ICSEAF period, has influenced time series data used in resource assessments of these stocks (Oelofsen and Staby, 2003; Butterworth and Brandao, 2003). Unreported catches of deepwater species in the South Pacific by international high-seas vessels, particularly in areas close to or beyond the EEZs such as the Louisville Ridge[6] might also have occurred.

Deepwater effort in these periods (pre-1980) almost certainly contributed to stock depletion, particularly affecting accumulated stocks of long-lived species such as orange roughy.[7] These vessels, which were the first modern day deep-sea operations, were large (up to 120 m) powerful fuel-inefficient vessels capable of deep tows using both mid-water pelagic directed nets and heavy otter trawl gear with rock hoppers and heavy steel bobbins. Abundance of deepwater stocks was high, technology was limiting but functional, and the economics was driven by volume and relatively low fuel costs and cheap crews.

More recently (since 1980) fishing techniques and technology have advanced enormously and this is reflected in the FAO catch statistics aided by more responsible reporting of catches. The development of the orange roughy fishery off both Australia and New Zealand since 1980 is perhaps the best (but not exclusive) example of advancements in deep-sea fishing. Even given the improvement in monitoring and effort limitation, unregulated high seas activity poses huge problems. The Tasman Rise controversy in 1999 (Annala and Clark, 2003) raised many issues related to deep-sea trawling and openly challenged the management and governance of deep-sea fisheries in the high seas. In a subsequent development from 1996, Australian, New Zealand and South African-flagged deep-sea equipped freezer trawlers began exploiting orange roughy and other deepwater species in the South West Indian Ocean (SWIO) (Japp, 2003). This fishery peaked quickly and declined rapidly as more and more high seas operators became involved (effort is believed to have peaked at about 35 vessels). This was primarily a seasonal fishery targeting winter aggregations of orange roughy.[8]

When catch rates of orange roughy declined, effort switched to alfonsino (*Beryx splendens*). Effort has since declined even further and trawling in the area is no longer economically viable for most operators. Clearly, of the three basic requirements for an effective deep-sea fishery, technology has played a role, but the main incentive was good catch rates combined with high product value. Many of deep sea SWIO operators very quickly lost interest when the returns (catch rates) declined and international fuel prices increased - the economic incentive was lost. It is a moot point that the declaration of eleven benthic protected deep-sea areas in the Indian Ocean (IUCN, 2006) came at time when the economic incentive to fish in the deep sea areas had already been lost (Figure 2).[9]

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[6] Noting that Annala and Clark (2003) reported an established deep sea fishery in this area from 1993.

[7] It is believed that although large volumes of orange roughy (for example) may have been caught by international high seas vessels from the 1950s to 1980s, markets for these species had not been developed. Catches were mostly processed as fishmeal, minced or discarded.

[8] Discussion at the Expert Consultation clarified the origins of the SWIO fishery unknown to the authors. It is understood that the SWIO grounds had been investigated prior to 1996 by New Zealand companies and that the initial target species was alfonsino.

[9] Noting the emphasis in "Benthic" protected areas as opposed to fully "Marine Protected Areas". Ref. Pers comm.. G. Patchel at the expert consultation. Dimensions and coordinates of the grounds protected are given in IUCN / SIODFA questions and answers communication (IUCN, 2006).

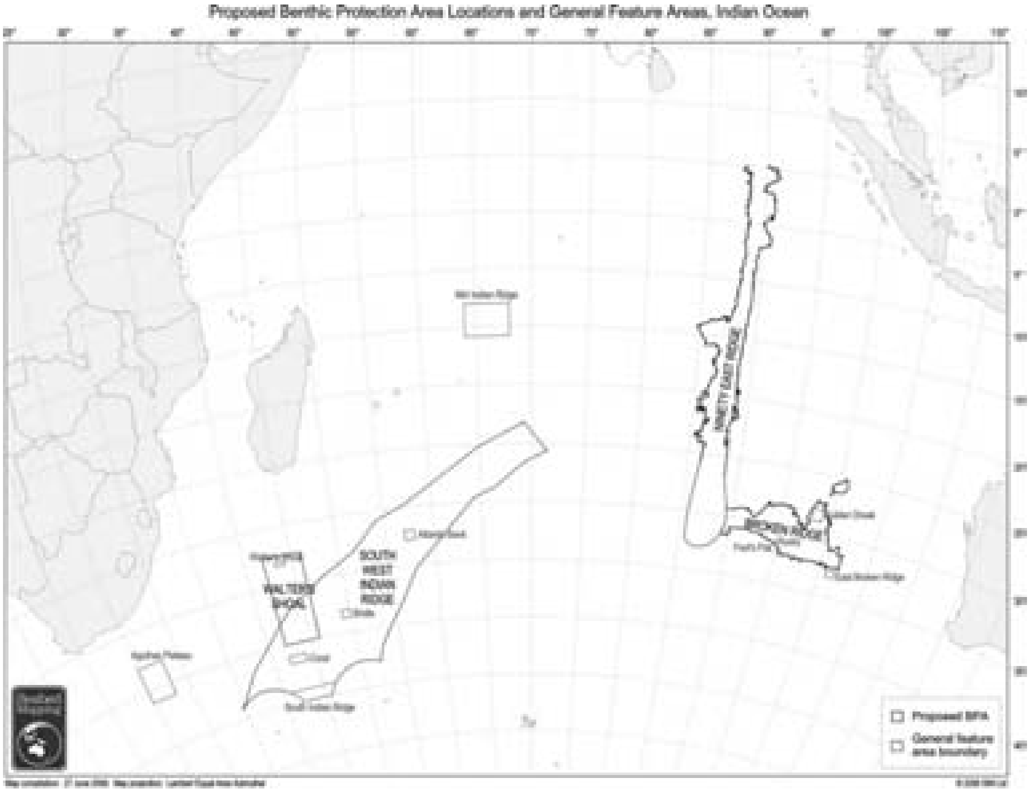

Figure 2. Declared benthic protected areas in the South Indian Ocean in collaboration with the *Southern Indian Ocean Deepwater Association (SIODFA)*

With respect to historical deep-sea effort it is generally believed that deep-sea fishing expanded rapidly in the last 10-20 years due primarily to factors such as new technology and surplus fishing vessel capacity. Although effort and technology are important factors, economics and market demand are, in this author's view, the main drivers of deep-sea fisheries. Technology provides the tools to catch efficiently, but ultimately distances offshore, catch rates and fuel costs will dictate global deep-sea effort. Nevertheless the development of a remarkable array of deep sea technology has advanced deepwater fishing as well as having increased the potential to fish even deeper than present.

4. DEEPWATER TECHNOLOGY

In deepwater fishing, emphasis is naturally placed on trawl gear, although the use of alternative gear types should not be ignored (e.g. demersal longlines and traps). Demersal trawling has developed primarily around the use and modifications of otter boards and warps (Thiele and Niedzwiedz, 2003). These modifications are sensitive to many different factors including hydrodynamics, length and tension of warps and door balancing (fixation points). Deepwater gear is heavy gear requiring combinations of bobbins, rock hoppers, warps and chains (Figure 3).

Efficient utilization of this gear requires a high level of skipper/fishing master skill particularly when positioning gear on seamounts or specific trawl lines to keep clear off foul ground. Skippers now have advanced acoustic tools, including 3-dimensional bathymetric charts, global positioning and multi-beam sounders (Figure 4), variable pitch propellers and thrusters to assist them.

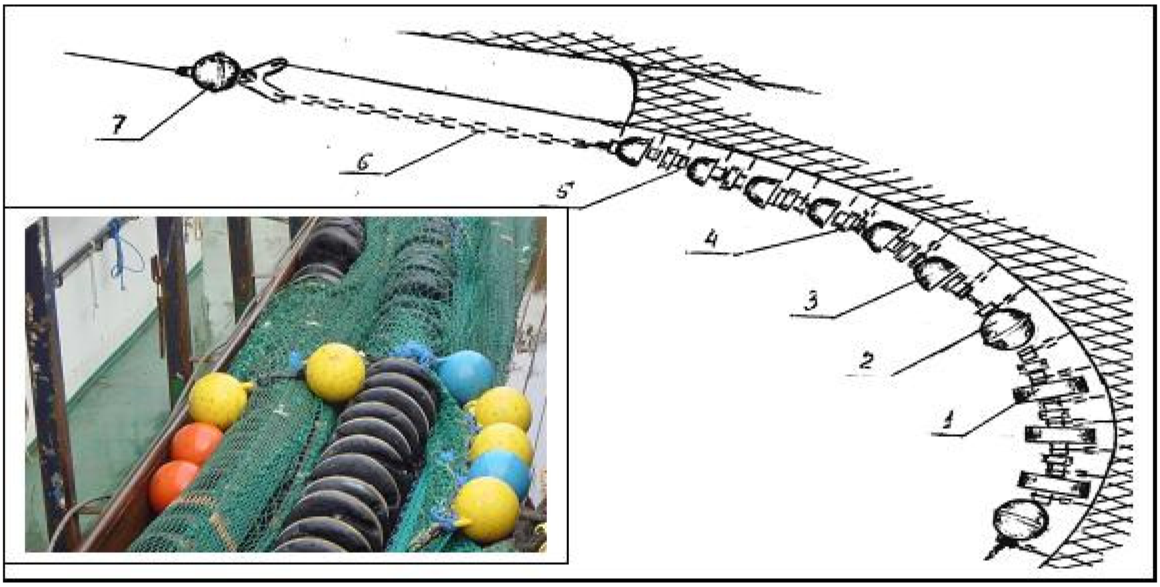

Figure 3. Typical deepwater trawl gear (head and foot ropes of an orange roughy trawl) - *schematic after Thiele and Niedzwiedz, 2003*. [1, bobbin (rubber); 2, spherical bobbin (metallic); 3, half spherical bunt bobbin (rubber); 4, rubber disk; 5, becket bobbin with chains; 6, chain; 7, bobbin-butterfly danleno]

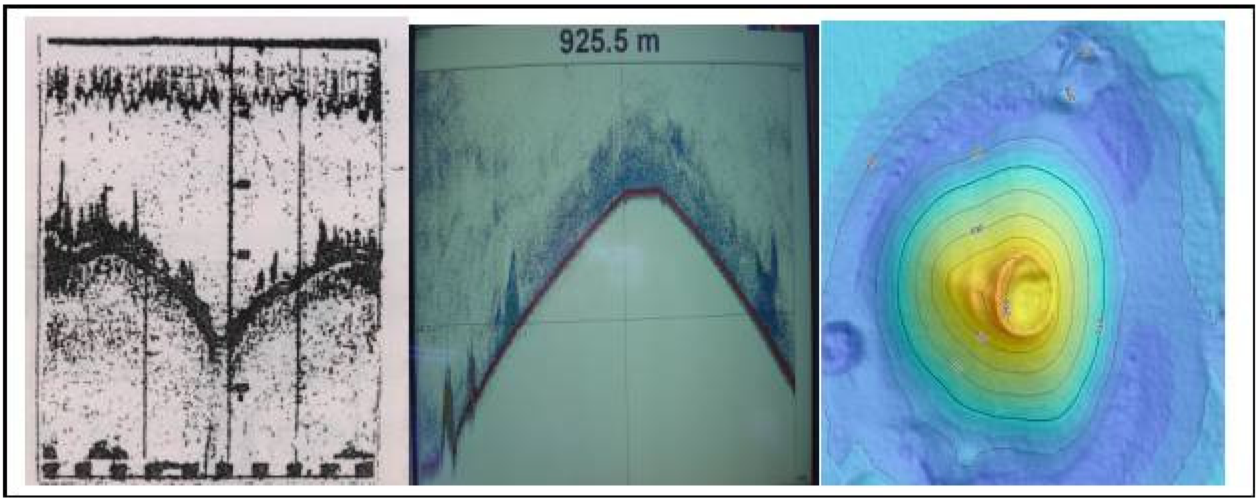

Figure 4. Echographs shown on three different displays and with different echo sounders. Scaling is important when interpreting the extent of, for example, seamounts. Often seamounts are incorrectly perceived as dramatic rises in the deep ocean whereas gradients are often more gradual than perceived and dependent on the tracking and vessel speed over sub-sea features. The figure (left) is a paper trace recording of the echo sounders used by the Russian high seas vessel off the Azores in 1970s, a seamount (center) off the Louisville Ridge (orange roughy targets) and an example of 3-D charting of a seamount (right).

Vessel and winch power, rather than vessel size, is important with most modern vessel constructions which are smaller and more fuel-efficient than older vessels. Control of gear deployed (warp length when trawling deep is generally 2-3 times the water depth) is essential, especially when pinpointing targets on seamounts and slopes (Figure 5).[10] Fish aggregations are often dense and skippers have learned to open and close gear to prevent excessive catches which can be as much as 60 t in less than a minute of bottom trawl time (Figure 6).

[10] Noting comments at the expert consultation that these diagrammatic representations are not fully descriptive of deep-sea targeting practices and that there are many variations with respect to species, depths and grounds and sub-sea structures fished.

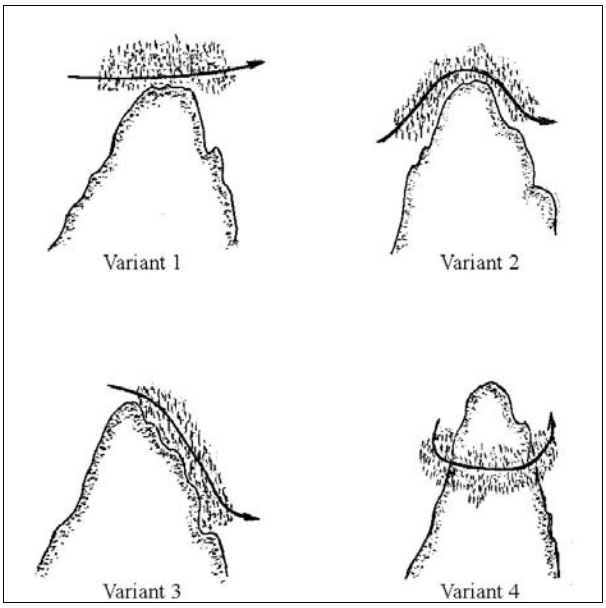

Figure 5. Typical distribution pattern of roundnose grenadier on the deep-water banks of the Mid-Atlantic ridge and trawling direction required based on target position on the seamount. (*taken from Oleg M. Lapshin and Viktor K. Korotkov. 2003. The results of deep sea fisheries development in Russia/USSR and related scientific research*.

Figure 6. A 40 t bag of orange roughy. Deep water trawling on seamounts requires precision navigation and experience in fish behaviour. Gear is often used to herd aggregations. Deepwater trawling is mostly done down slopes and must also accommodate currents. Nets are monitored for fullness to avoid over-catching with the use of escape panels to prevent unnecessary wastage.

5. DEEP-SEA EXPLOITATION - IMPACTS ON HABITAT AND BIODIVERSITY

Presently, trawling, and particularly deep-sea trawling, is under enormous pressure globally. Recent declarations by the United States of America, the European Union, Australia and New Zealand have called for bans or stricter controls on deepwater trawling on the high seas. As mainstay species like cod and hake become depleted by overfishing, deepwater species such as forkbeard, orange roughy, black scabbardfish and roundnose grenadier are also being targeted. This global trend to halt or at least severely limit trawling and deep-sea exploitation seems to be gathering momentum and it is in the interest of fishers and managers to proactively address the problem.

Addressing these concerns is complicated by the high degree of variability in the deep-sea environment. This variability includes not only oceanographic conditions, but also habitat types that are associated with high biodiversity. The sea bed, for example interacts with currents and weather to form a variable and dynamic deepwater fisheries habitat. Deepwater current regimes influence the distribution of many deepwater species. Variability in currents occurs at many different levels, from local or diurnal shifts around seamounts, dynamic upwelling on continental slopes and on the largest scale, global circulation patterns.[11] Many organisms at these depths survive with low light intensity and tolerate low temperatures. It is possible that between 500 000 and 100 million species may inhabit deep-sea areas (IUCN press release reported in Washington Post, 2006). Because this variability occurs on a range of scales the distribution of the many species in the deep-sea environment has in many instances, evolved unique biological and behavioural adaptations. It is these adaptations that often make them vulnerable to over exploitation (such as aggregating behaviour, slow growth and low fecundity).

[11] Industry observers have noted that shifts in bottom temperatures in the South West Indian Ocean significantly affect orange roughy availability and that these temperatures seem to be associated with the periodic global circulation patterns of deep ocean currents.

Deep-sea resources found off the continental shelves evolved relatively undisturbed until the mid 20th century. The accumulated biomass of species such as orange roughy and the deep sea cods and the many other species unique to these depths was sustained within the deep-sea ecosystem. The relatively recent exploitation of these species is seen by many as unsustainable, and it is thought to be only a matter of time before they are mined out completely. Further, because of the difficulty in accessing the deep-sea environment quantification of, for example, biodiversity and stock size (biomass) is extremely difficult. Advances in fishing technologies and the efficiency of fishing gear have also reduced refuges for many of the target species (habitat destruction). However, some observers and scientists believe that it is this precision of fishing operations that in fact has the potential to contribute to the sustainable management of deep-sea fisheries. The innovative use of technology which might include *in situ*, analytical and laboratory studies is likely to reveal much about deep-sea species and ecosystems (Shotton, 2003). Appropriate use of this technology may also facilitate the evaluation of the effects of environmental variability on fisheries. Carter and Clark (2003) for example have demonstrated how in the New Zealand deep-sea environment, the sea bed is complex and interacts with currents and weather systems to form variable and dynamic deep-ocean habitats. With technology, it is now possible to define the shape and position of sea bed features that can be resolved on a relatively fine scale such that detailed habitat maps are now possible. Making use of both observations and models, our understanding of the ocean and its interaction with climate has also improved dramatically and can be used to improve our evaluation of environmental effects on fisheries. Australia has been a leading proponent of the Ecosystem Approach to Fisheries (EAF) and has developed policy integrating environmental assessments into their fisheries management systems (Wilkinson, 2003).

Because of the many difficulties in managing fisheries and ecosystems there are now strong moves to create sanctuaries or marine protected areas (MPAs) that can be both a fisheries management and biodiversity conservation tool. These MPAs can take many different forms and can be used to achieve many different objectives, e.g. the recently declared MPAs in the South Indian Ocean. They may range from simple seasonal closed areas to reduce impacts on spawning aggregations, to completely protected (closed) areas in which all forms of usage is forbidden. In New Zealand, orange roughy exploitation is strictly controlled by a Quota Management System (QMS) with Fisheries Management Areas (FMAs) and Quota Management Areas (QMAs) that limit both target and bycatch species (Clement, 2002). The New Zealand Ministry of Fisheries has worked closely with the orange roughy fishers closing fishing grounds and monitoring stock recovery. Orange roughy fisheries have a poor track record with numerous examples of stock collapse, e.g. St Helens Hills of Tasmania, Namibia and the South West Indian Ocean. Shotton (2003) summarised the discussion on MPAs as follows:

> "If closed areas are to be used, managers ideally need to understand stock structures, movements and long term migrations to determine critical habitats, how large an area should be closed, and whether there is scope for seasonal closures as a management tool. Their establishment must be accompanied by baseline surveys (e.g. population size, structure) at time of closure in order to be able to determine the effects of closure. Where such surveys are not possible, the establishment of large closed areas (particularly if possible before fisheries become established) may be very important for species conservation and reducing the overall impact of fisheries on deepwater stocks."

6. BIOLOGY, FISH BEHAVIOUR, MARKETS AND ECOSYSTEM EFFECTS OF THE EXPLOITATION OF DEEP-SEA FISHES

Fundamental to the understanding of deep-sea fisheries is the biology and behaviour of the many different species exploited. This understanding is required beyond just target resources. Internationally fisheries management is moving towards managing ecosystems rather than target resources (EAF or the Ecosystem Approach to Fisheries Management, FAO 2003). This approach becomes even more difficult in the deep sea as our knowledge of the biology and life history strategies of many deep-sea species is relatively poor, simply because we do not fully understand the complexity of deep-sea habitats, which is exacerbated by the paucity of, and difficulty in obtaining good information. Nevertheless there is still a vast amount of biological information on many species and some, such as orange roughy, have been thoroughly researched. Even so, there are still gaps in our understanding relating to behaviour (aggregating), recruitment, spawning processes and age and growth (Paul *et. al*., 2003).[12] A common trend in most species found on continental shelves is for larger, older fish to migrate into deeper water. This is true for most hake species and there is some evidence suggesting that sex ratios of the larger fish are skewed towards females, further emphasizing the potential impacts on stocks when fishing effort shifts into deeper water.

Slow growth also implies low productivity (which has also been also linked to low fecundity). This increases the vulnerability of these species and stocks to overfishing (when the mining out of accumulated biomass exceeds the rate at which new biomass is regenerating). In many instances the references to these basic characteristics (slow growth, low fecundity, high age at first maturity, etc.) are often used loosely. Gordon (2003) summarised the state of knowledge of many of the families of common deep-sea fishes clearly illustrating how much uncertainty there is in our knowledge and understanding of the biology of most species. Gordon (2003) using the ICES Deep–Sea Working Group species vulnerability ranking, concluded that the squalid sharks, orange roughy and grenadiers could be classified as biologically vulnerable whilst others such as scabbardfish and ling were much less so and stocks in these groups are probably more likely to sustain exploitation (assuming under a controlled management and effort regime).

With respect to ecosystem effects in general, behavioural strategies such as the vertical migration of mesopelagic animals, is an important component of energy transport from surface waters to deeper levels. This implies very broad effects on deep-sea ecosystems. Sea surface productivity, upwelling regimes, continental shelves and slopes etc. will all have critical inputs to the food availability in deep-sea environments. Whilst stock assessment or management procedures may be able to provide good bases for decision-making, the collection of appropriate ancillary biological data to be used in more comprehensive analyses may be crucial for elucidating patterns in population distribution and viability (Shotton, 2003). With regard to EAF in general, participants in Deep Sea 2003 concluded:

> "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, in particular, to reduce it to appropriate levels where necessary. In order for this to happen, it is essential to develop better integration of assessment and management of marine resources with appropriate management frameworks that ensure single stock management whilst taking account of wider environmental or ecosystem issues".

7. DEEP-SEA FISH SPECIES GROUPINGS AND GLOBAL TRENDS IN DEEP-SEA CATCHES

Quantifying deep-sea catch and effort is problematic for the reasons already described in the preceding sections. The following assessment of global trends in deep-sea catches is based only on the FAO databases. We tried a different approach to that used by Garibaldi and Limongelli (2002) who looked at trends in oceanic captures and clustering of Large Marine Ecosystems (LMEs). We focused on catch trends in the main oceanic areas (Annex 1, Figure 12-14) by firstly identifying the]main deepwater species only (no large pelagic species or crustaceans) and then grouping and ranking by Order (a similar approach to that of Gordon, 2003). Within each Order we identified the main deep-sea species groupings (Families) and then reverted to the individual species trends where emphasis was considered relevant. This allowed us to make broad comparisons between oceanic areas as well as noting differences between northern and southern hemisphere deep-sea effort. It is stressed that

[12] Paul *et al.* estimated orange roughy age > 70 years and several other species such as cardinal (*Epigonus* sp.) up to 50 years and Rubyfish as much as 80+ years.

within the Orders used there is certainly some overlap with species that historically were caught in relatively shallow seas, but which are now targeted both on and off the shelf, e.g. cods and hakes. Garibaldi and Limongelli (2002) did define many deep-sea species, but also included many of the meso-pelagic species such as lantern and light fishes which were excluded from this analysis.

In Table 1 we split and rank, by catch volume, the orders and families of the dominant deep-sea species reported in the FAO Capture Fisheries Production database. We have also given the different Families within each order an arbitrary "Market Value" ranking based on as far as possible our experience. These rankings are by no means concise, and are only used as relative indicators between groups. The dominant deep sea Order are the Gadiformes that can be split between the Gadidae (cods, whiting, saithe etc), the hakes (merluccidae) and grenadiers (macrouridea) (Figure 7).

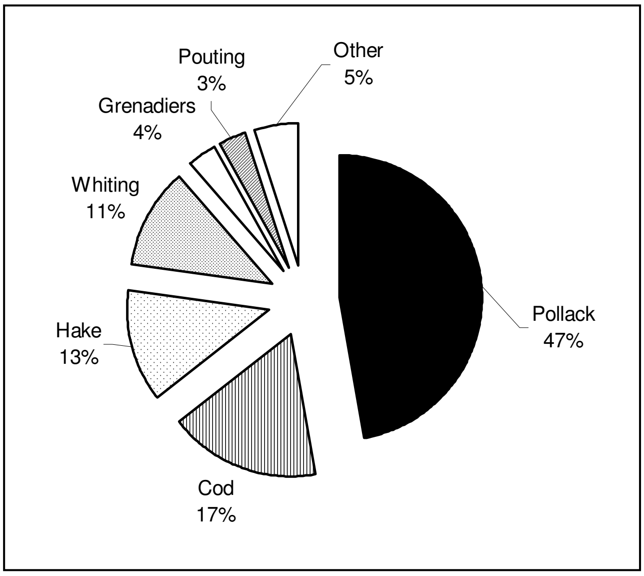

Figure 7. Global Proportions of reported catches of the main deep sea species groups within the Gadidae

With respect to volumes landed, the gadiformes are second only to the Trichuridae (in the Order Percifomes, Table 1) comprising mostly frostfish, hairtails, cutlass fish and many other similar species that are either bathy or meso-pelagic and are caught in large numbers in different oceans using predominantly mid-water trawl gear. With respect to market value however the gadiformes are amongst the most highly valued species and are broadly categorised and sold as "whitefish". Species such as Atlantic and Pacific cod, pollack, hake and hoki compete on the international markets.[13] The Beryciformes (Table 1) comprise the two most definitive deepwater species sold on international markets, these being the orange roughy (Trachichthyidae) and alfonsino (*Beryx* sp.).

Orange roughy catches were first reported from the late 1970s, and alfonsino about 10 years earlier (targeted by the Russian exploratory high seas vessels as noted earlier). Although orange roughy catches peaked in about 1990, catches have since declined as our understanding (Figure 8) of the species and the impacts of exploitation has improved with more stringent management regimes been put in place (New Zealand effort is the highest, with relatively small quantities caught in other parts of the world, including Namibia, Chile, Australia and the North East Atlantic – Figure 9, after Branch, 2001).

[13] Pollack, Hoki and South African trawl hake all have Marine Stewardship Council (MSC) certification.

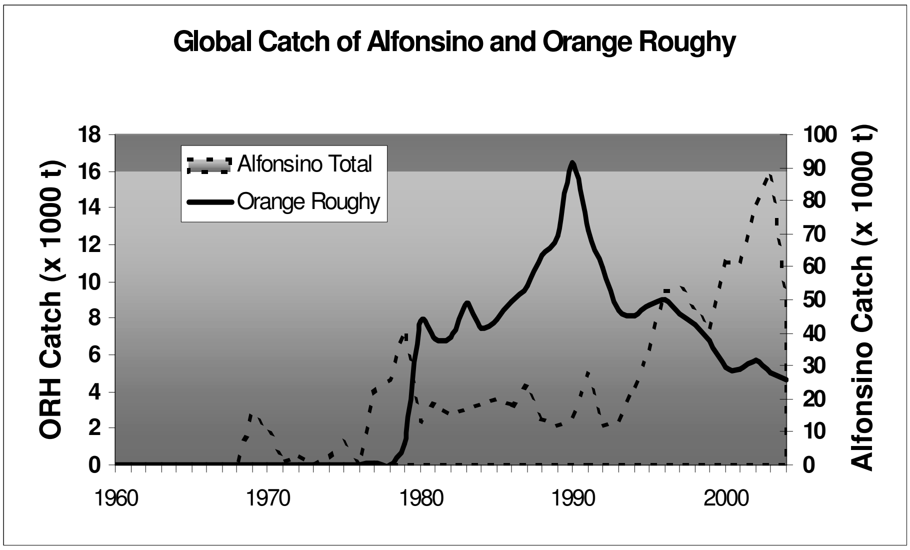

Figure 8. Historical catches (global) of orange roughy and alfonsino

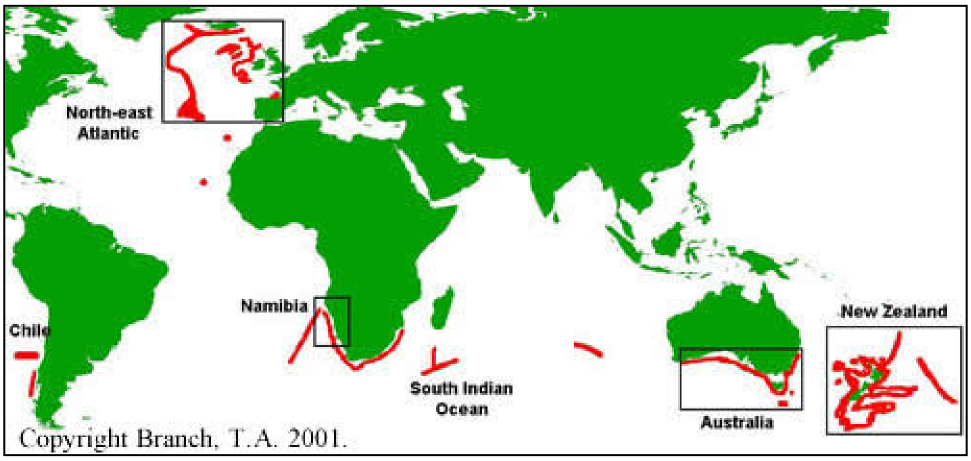

Figure 9. Global distribution of orange roughy

There is an extensive amount of literature and associated research conducted on orange roughy, primarily because of this species' sensitivity to over-exploitation and the associated difficulties in assessing and managing the stocks. Orange roughy are one of the highest valued commercially-caught fish products (with the exception of perhaps Patagonian toothfish) and are sold predominantly in the United States of America. Because aggregations are mostly targeted, catches are often clean with low bycatch (Figure 6 and Figure 10a). However, in many fishing areas, particularly seamounts, catches are often mixed with significant quantities of deepwater dories, cods (the "ribaldo", Moro moro is a common bycatch) as well as Trichuridae (Figure 10b). Alfonsino (Figure 10c) are also a popular product, but are sold mostly in Japan and the Far East (Europe and United States of America are also strong markets for Alfonsino). With regard to orange roughy markets, the product is easily processed and can be frozen, then thawed for reprocessing into frozen fillets (mostly "shatter packs") and value-adding. Alfonsino by comparison is generally not value-added and is sold whole or in headed and gutted form (Figure 10c).

Figure 10. Commercial catches of : a) (from far left) clean orange roughy, b) mixed orange roughy with bycatch and c) clean alfonsino frozen whole in cartons for export.

Trends in the global catches of the other major Orders (Table 1) are shown in Figure 11. Dories are a common group caught in trawls and catches can be quite easily separated between those caught in deepwater and the more common species traditionally caught on the shelf (e.g. *Zeus capensis*). The deepwater dories are found in most oceanic regions, and are caught and processed in viable volumes in New Zealand and a few other countries. In New Zealand oreo dories are strictly managed under the Quota Management System and are mostly caught as a bycatch in the orange roughy-directed trawls (although it is possible to target some species). Since 1981 (Figure 11) there are no indications that catches are declining (noting that there are quota limitations).

Scabbard fish (Perciformes – Trichuridae) catches worldwide are substantial and although they have been included as a deepwater species, they are caught extensively in mid-water, in relatively shallow and deep-sea areas including on and off the continental shelf. They are often associated with other mid-water species such as horse mackerel (*Trachurus* sp.). Total catch has increased since mid-1990 and is now over 1.5 million tonnes per annum. Other species in the same group include several species targeted by deep-sea longliners, such as the oilfish (*Ruvettus pretiosus*) and the Escolar. Other minor Perciforme species targeted (Figure 11) in deepwater include wreckfish, boarfish (also called armourheads) and cardinals (*Epigonis* sp.). Wreckfish (*Polyprion* sp.) are also caught in most oceans and are a deep sea bass (rock cod) with a high market value. They are difficult to catch and are mostly caught with dropper lines. Catches of armourhead have declined in the last decade – this small migratory shoaling species is often found on or around seamounts and has been heavily fished in the Pacific and north Atlantic oceans.

With respect to catch trends, the Lophiformes (deep sea anglers) have been increasingly targeted in the last decade (Figure 11) to the extent that of all the minor deep-sea species (excluding gadiformes and hairtails) have been the most heavily targeted group (this trend is undoubtedly associated with the high market value placed on species such as monkfish and the New Zealand stargazer). Similarly the cusk eels (*Ophididae*) have also been increasingly targeted by deep-sea fisheries with catches increasing steadily since the 1970s. Cusk eels are a frequent bycatch in deepwater trawls, but are also specifically targeted in some fisheries[14].

The Scorpaeniformes are a commonly caught deepwater species, although comparatively, catch volumes are small. Sablefish are an important fishery on the west coast of the United States of America and blue rock fish (*Helicolenus dactylopterus*) are caught extensively on hard grounds by trawl and longline in all oceans. Globally however, catches of deepwater rock fishes are declining (Figure 11).

[14] The New Zealand ling (*Genypterus blacodes)* and the South African kingklip (*G. capensis)* are significant deep-sea commercial species reported to be long-lived and aggregate seasonally.

The last deepwater species groups considered are the chondrichthyans comprising mostly deepwater dogsharks (Squalidae), the Chimaeriformes and the skates and rays (Rajiformes). Commercially, these species have low market ranking (Table 1) and volumes reported are also relatively low. This is, however, not believed to be a true reflection of the commercial mortality of these species that have historically been discarded and misreported in most fisheries (Cavanagh and Kyne, 2003). The global (FAO) data do not suggest any trends in the reported landings. Chondrichtyans make up a significant component of deep-sea biodiversity with numerous species classified critically endangered or vulnerable.

8. DEEP-SEA EXPLOITATION BY OCEANIC REGION

In Figures 12-14 we illustrate decadal trends by oceanic region. The intention here is to identify trends in the total catches in each area with particular reference to the status of the main deep-sea species in the last 10 years[15].

In the Eastern Pacific (Figure 12) catches are dominated by gadiformes, more specifically pollock, cod, hakes and grenadiers. Catches peaked at 20 million tons in the preceding decade and in the last 10 years, have started to slowly decline. The situation is quite different in the Southeast Pacific where the dominant gadoid is hake - catch volumes are increasing, but at about 4.5 million tons, catches are significantly lower than the total deep-sea fish mortality in the Northeast Pacific. In the Central Eastern Pacific catch volumes are even lower than in the temperate regions with rock fishes dominating.

In the North Western Pacific decadal catches are nearly double that reported for the Northeast Pacific and are also dominated by pollock and cod. Hairtail adds a large proportion to the catch. The trend however, shows a sharp decline in catches in the last 10 years from a peak of about 50 million tons to <38 million tons. As in the Eastern Central Pacific, catches in the Western Central Pacific are dominated by scabbards and hairtails. The catch trend is strongly upward in the last decade. Total volumes are much lower than the more temperate northern and southern oceanic regions (approximating 500 000 tonnes). The Southwest Pacific is the most diversified of all the deep-sea areas. Total catch of deep-sea species in the last decade increased marginally to just over 4 million tonnes comprising mostly hoki (merluciddae) with comparatively smaller volumes of orange roughy, alfonsino, oreo dories and other deepwater-directed bycatch species. As in the other oceanic regions the data suggest that volumes taken in the northern oceanic regions are substantially higher than in the southern oceans.

Historically, in the Northwest Atlantic, catch volumes were as high as the North East Pacific, with similar species targeted (cods, pollock, hakes) and a relatively small proportion of scorpaenids. Catches of deep-sea species in this oceanic region have declined steadily in the last three decades, primarily associated with the collapse of the cod fishery. Catch volumes in the Western Central Atlantic are comparatively low (100 000 t in 10 years) but have nevertheless increased significantly in the last decade (comprising of predominantly scabbard fish).

The Indian Ocean (Figure 14) is covered by two reporting areas; the Western Indian and Eastern Indian. In both areas deep-sea catches are dominated by hairtails with only relatively small proportions of grenadiers, orange roughy and alfonsino reported.

In the Northeast Atlantic (Figure 13) total deep-sea catch has been sustained in the last decade at nearly 38 million tonnes. Species targeted are similar to the Northeast Pacific (cods, pollack, whiting and hake). In the Central Eastern Atlantic the species targeted differ somewhat to the species in the Central Pacific with a higher proportion of hake and whiting although still dominated by scabbard. Total catch in the last decade has declined although at about 700 000 tonnes, is comparatively lower

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[15] Note that our graphs reflect decadal catch volumes (cumulative totals) and do not reflect inter-annual catches.

than both the northern and southern temperate water deep-sea catch estimates. Hake dominates the catches in the South (West and East) Atlantic. In the South West catches have increased since the 1970s and in the last decade approximated 7 million tons. The trend in the South East Atlantic is the opposite having peaked at about 7 million tons in the 1970s[16] and declining. Presently the decadal catch approximates 3 million tons (predominantly hakes) in the Southeast Atlantic.

The last region of interest is the Mediterranean and Black Seas (Figure 13). Catches in this region in the preceding decade peaked at over 800 000 tonnes and in the last 10 years have declined to nearly 600 000 tonnes (60 000 tonnes annually). Catches in this area consist mostly of whiting and hake.

In summary it is clear that catch volumes of what can be defined as deep sea species are significantly higher in the northern temperate water oceans (comprising of predominantly gadoids) than in the southern oceanic areas. In contrast, the southern oceanic regions catches have historically been much lower and have been dominated by hakes. Although the species diversity of deep-sea resources appears similar in most oceans, reported commercial catches in the southern oceanic regions suggest a greater diversity of fishing activity and species targeted. Stocks in the southern oceanic regions also show less indications of stock “stress” with both lower volumes being taken and generally fewer downward trends in the last decade. In the central oceanic regions, deep-sea volumes caught are significantly lower than in the temperate seas and are dominated by large volumes of hairtails and scabbard fishes. These data suggest that in the last decade there has been a shift away from species such as the scorpaenids (which appear to have declined) to targeting on scabbards and hairtails.

These observations suggest not only a disparity between northern and southern hemisphere historical fishing effort, but possibly also a fundamental difference in regimes with significantly higher productivity in the northern oceans.

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ANNEX 1: Figures and Tables

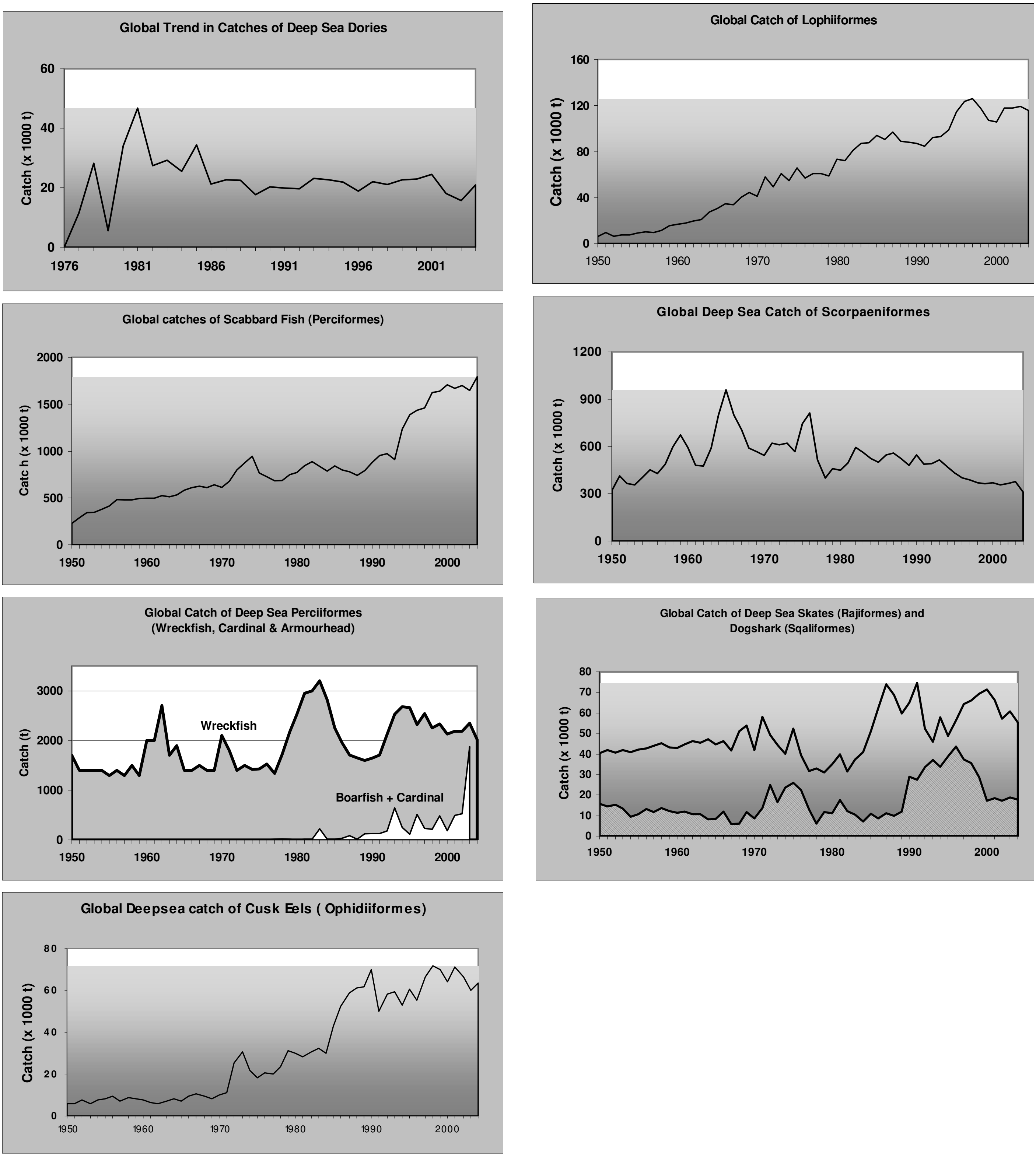

Figure 11: Global trends in deep sea catches of the main fish orders (excluding the Gadiformes and Beryciformes)

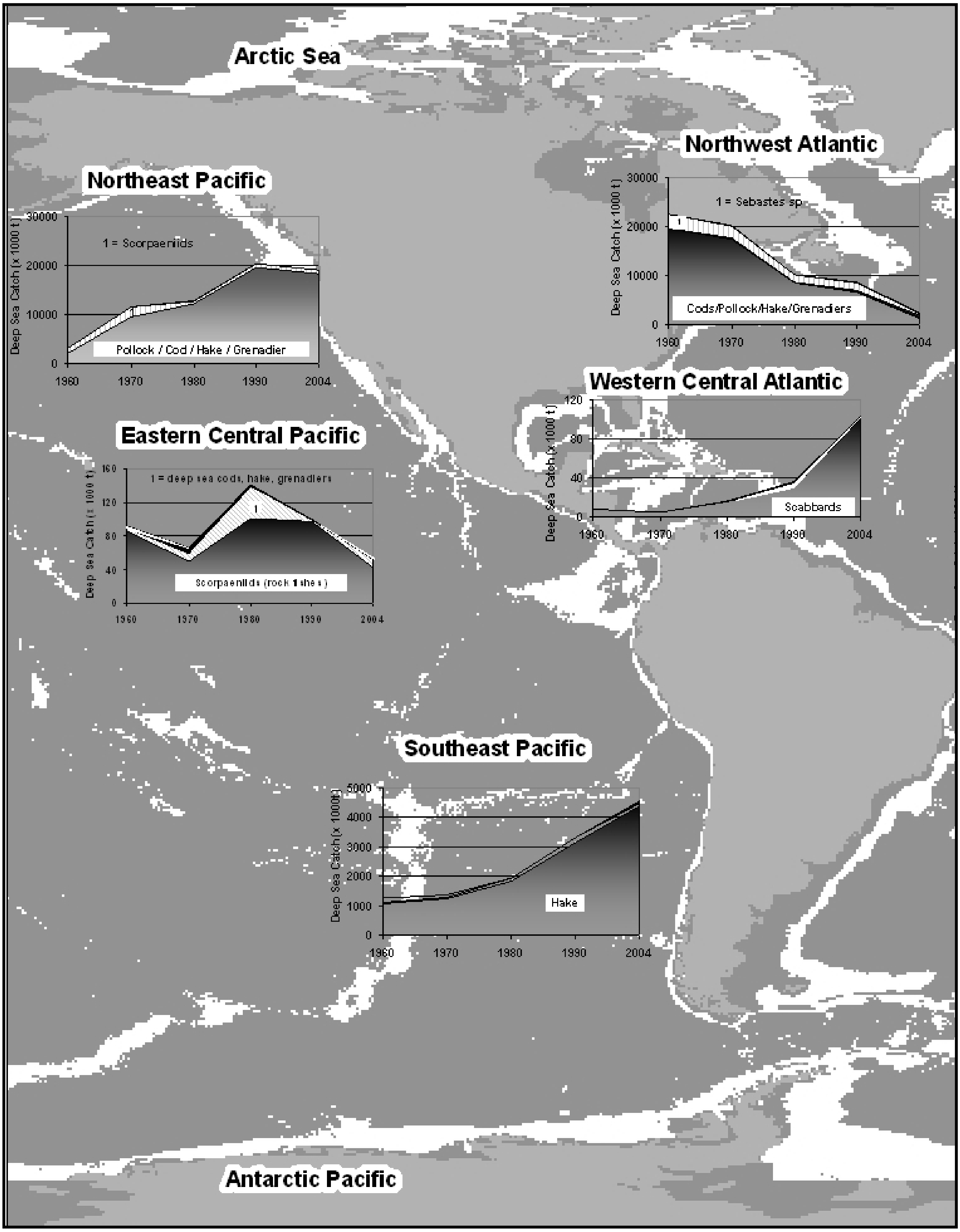

Figure 12. Decadal trends in deep sea catches for the western Pacific and eastern Atlantic oceans.

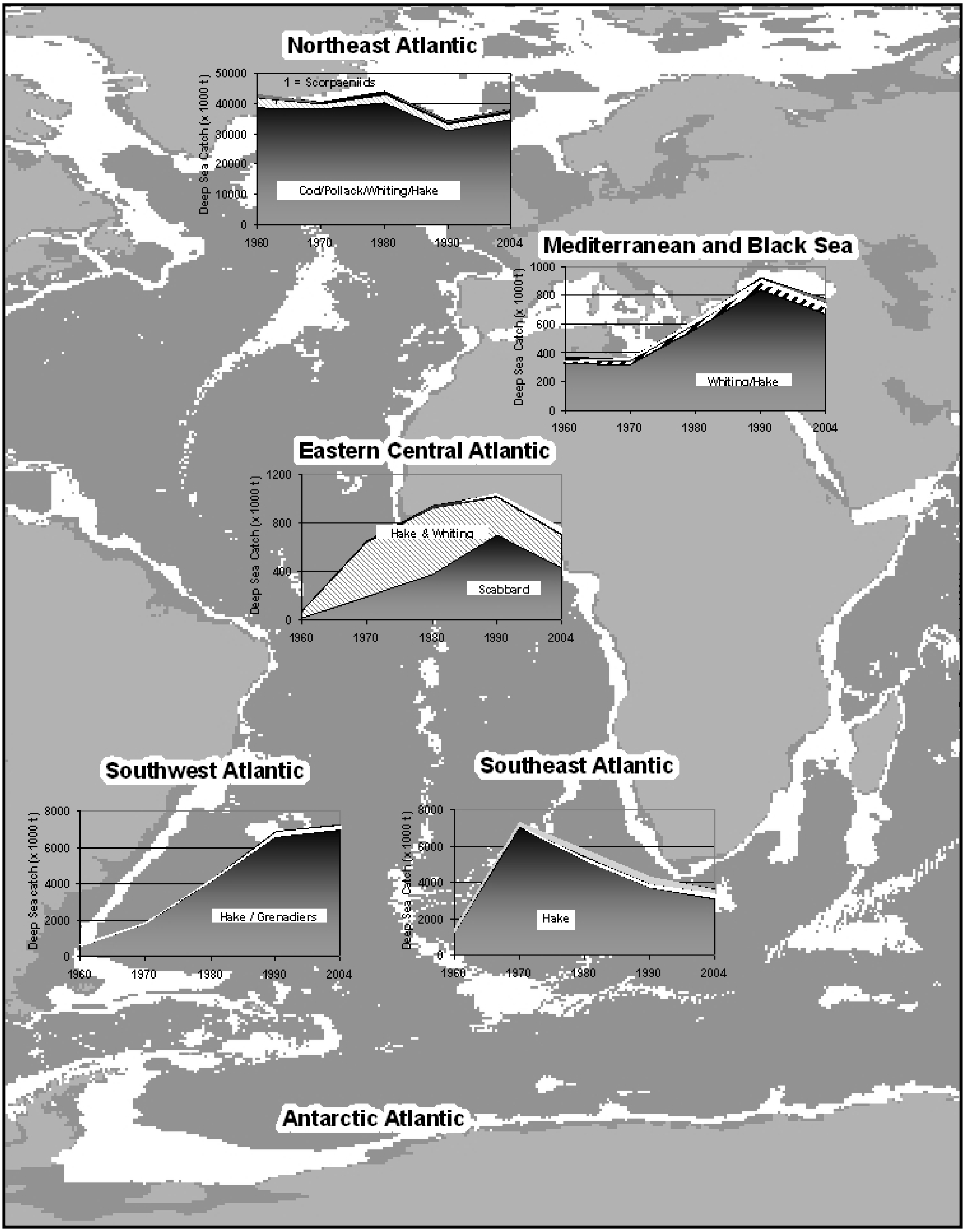

Figure 13. Decadal trends in deep sea catches for the Atlantic Ocean, Mediterranean Sea and Black Seas.

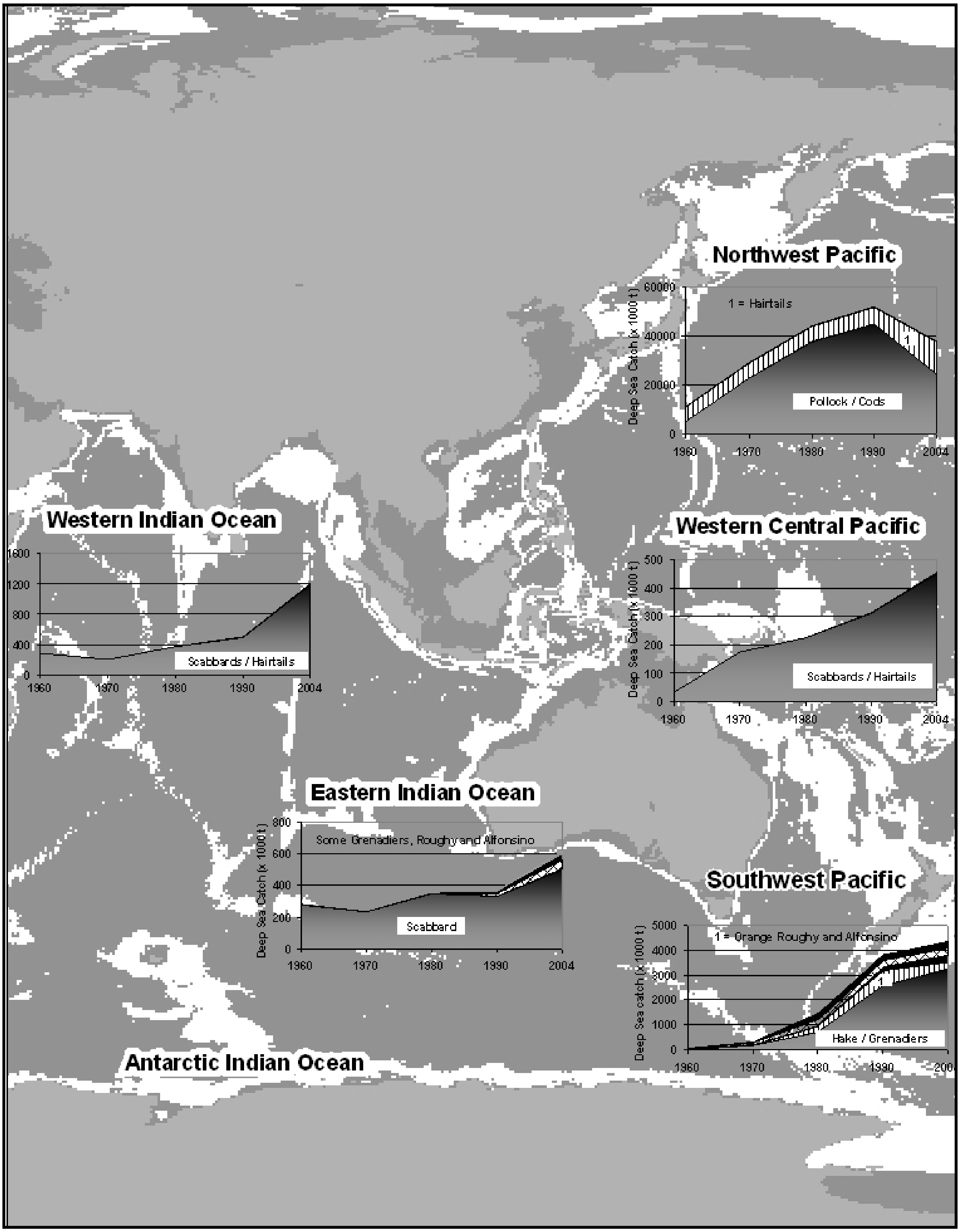

Figure 14. Decadal trends in deep-sea catches for the Indian and Western Pacific Oceans areas.

			Relative Ranking (5 = highest, 1 = low, O = Negligible)			
Order	**Families**	**Depths**	**Catch Volume**	**Market Value**	**Trend (volume)**	**Common Names**
Gadiformes	Gadidae	Shelf,Slope,Seamounts	4	4	Declining	Cods, Whiting, Pollack, Saithe, Pouting,Pollock, Ribaldo (moridae)
	Merluccidae	Shelf and Slope	3	4	Stable/Increasing	Hakes
	Macrouridae	Slope	4	3	Stable/Increasing	Grenadiers
Beryciformes	Berycids	Slope	3	4	Declining	Alfonsino
	Trachichthyidae	Shelf and Slope	3	5	Stable/Declining	Orange Roughy, Slime heads
Zeiformes	Zeidae	Slope & Seamounts	2	3	Stable	Deepwater Dories
Perciformes	Polyprionidae	Shelf and Slope	2	5	Increasing	Wreckfish
	Pentacerotidae	Seamounts	2	4	Decreasing	Armourheads, Boarfish
	Apogonidae	Slope & Seamounts		2	Stable or Decreasing	Cardinals - epigonus sp
	Gempylidae	Shelf,Slope,Seamounts	5	3	Increasing	Snake mackerels, Snoek
	Trichuridae	Shelf,Slope,Seamounts	5	2	Increasing	Escolar, Oilfish (ruvettus), Snoek, Gemfish, Frostfish, Buttersnoek, Cutlass
Ophidiiformes	Ophidiidae	Shelf,Slope,Seamounts	3	2	Uncertain	Cuskeels,Ling, Botrulas,Bathitids
Lophiiformes	Anglers	Shelf,Slope,Seamounts	3	4	Increasing	Monkfish, Stargazers
Scorpaeniformes	Sebastinae	Shelf,Slope,Seamounts	3	3	Increasing	Sablefish, Rock fish
Stromatoidea	Ruffs	Slope & Seamounts	2	2	Uncertain	Bluenose, Black ruff
Nototheniidae	Icefishes	Shelf and Slope	3	3	Increasing	Toothfish and Icefish
Squalidae	Squaliidae	Shelf,Slope,Seamounts	1	0	Uncertain	Dogshark
Chimaeriformes	Chimaeriidae	Shelf,Slope,Seamounts	1	1	Uncertain	Chimaera’s
Rajiformes	Rajiidae	Shelf,Slope,Seamounts	1	1	Uncertain	Rays