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Review

Deep-sea seamount fisheries: a review of global status and future prospects

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ABSTRACT. Seamounts support a large number and wide diversity of fish species. A number of these species can form aggregations for spawning or feeding and are the target of large-scale trawl fisheries. Since the 1970s, seamounts throughout the worlds' oceans have been explored for commercial resources, starting with efforts by the Soviet Union and Japan, which deployed distant water fleets around the world. Since then, a large number of countries have pursued fisheries on seamounts, especially in the deep sea. The total cumulative catch from seamount trawl fisheries exceeds two million tonnes. Catch histories for many deep-sea species show rapidly declining landings, and careful management is required to increase the chances of sustainable fisheries. The low productivity of many seamount species limits the prospects for the large-scale exploitation of fish and invertebrate resources on seamounts.

Keywords: deep-sea, fisheries, seamounts, fisheries management, sustainability, orange roughy, *Hoplostethus atlanticus*.

Pesquerías de aguas profundas realizadas en montes submarinos: revisión global de su estado y perspectivas futuras

RESUMEN. Los montes submarinos constituyen el hábitat de una vasta y amplia variedad de especies ícticas. Parte de estas especies pueden formar agregaciones reproductivas o alimenticias, siendo objeto de importantes pesquerías de arrastre. A partir de la década de los 70´ los montes submarinos en los diversos océanos fueron explorados en busca de recursos comerciales, labores que se iniciaron con la expansión de flotas de aguas distantes de la Unión Soviética y Japón alrededor del mundo. Desde ese momento, un gran número de otros países ha desarrollado pesquerías en montes submarinos, especialmente en aguas profundas. La captura total acumulada que se ha extraído en los montes submarinos excede a dos millones de toneladas. La historia de las faenas pesqueras realizadas en numerosas especies de aguas profundas muestra una rápida disminución en los desembarques, razón por la cual requieren de un cuidadoso manejo para incrementar la oportunidad de lograr la condición de pesquerías sustentables. La baja productividad observada en diversas especies indica una limitada posibilidad de desarrollar pesquerías a gran escala, tanto de peces como de invertebrados, en los montes submarinos.

Palabras clave: aguas profundas, montes submarinos, pesquerías, manejo pesquero, sustentabilidad, orange roughy, *Hoplostethus atlanticus.*

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INTRODUCTION

Seamounts are prominent features of the seafloor throughout the oceans of the world. Their numbers are unknown, but recent studies based largely on satellite altimetry have estimated that there could be tens of thousands of large seamounts (Wessel, 2001; Kitchingman & Lai, 2004; Hillier & Watts, 2007). Their distribution is widespread throughout the world's oceans, especially in the Pacific (Fig. 1).

Seamounts support a large number and wide diversity of fish species. A total of almost 800 species have been recorded from seamounts (Froese & Sampang, 2004; Morato *et al*., 2006; Morato & Clark, 2007).

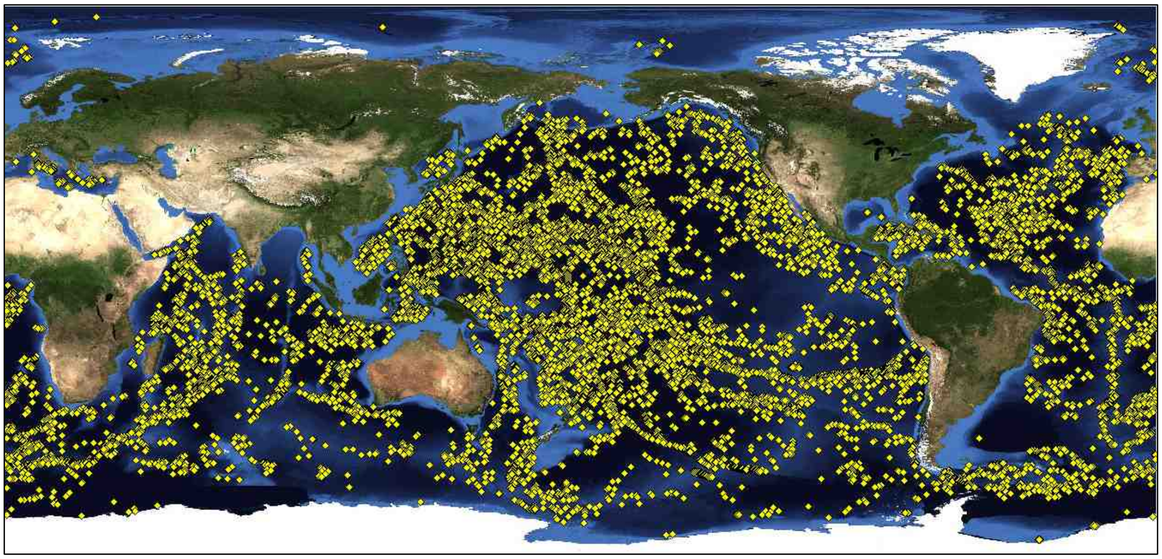

Figure 1. Estimated global distribution of large seamounts (elevation > 1500 m). Based on data from Kitchingman & Lai (2004).

Figura 1. Distribución mundial estimada de grandes montes submarinos (elevación > 1500 m). Según datos de Kitchingman & Lai (2004).

Most of these also occur widely on the continental shelf and slope habitat, but seamounts can be an important habitat for commercially valuable species that may form dense aggregations for spawning or feeding (Clark, 2001) and on which a number of large-scale fisheries have developed in the deep-sea.

Many of these fisheries, however, have not been sustainably fished or managed. A number have shown a 'boom and bust' pattern, with catches rapidly developing and declining within a decade (e.g. Uchida & Tagami, 1984; Clark, 2001; Vinnichenko, 2002a). These patterns have raised concerns over whether such fisheries can be sustainable (e.g. Roberts, 2002; Gianni, 2004; Stone *et al.*, 2004).

This paper briefly describes deep-sea seamount fish and trawl fisheries, reviews aspects of their sustainability, discusses what is required for effective management of both fisheries and the seamount habitat, and considers prospects for large-scale commercial exploitation of fish resources on seamounts. The study is restricted to demersal finfish, although seamount fisheries also occur for surface and midwater fish, crustaceans, and squids (see Rogers, 1994 and papers in Pitcher *et al*., 2007).

Description of seamount fishes

The definition of "deep sea" varies between organizations and countries. The FAO criterion is beyond the continental shelf/slope break, typically occurring at about 200 m. However, this depth-limit means a large number of shallow-water species are included where their depth distribution extends beyond 200 m. Hence, in this paper, the focus is on a more ecological definition that recognizes fish with low productivity relative to inshore continental shelf species, which are typically deeper than 400-500 m (FAO, 2008) (Table 1). It is not possible to generalize about biological characteristics, as deepwater seamount species span a wide range of productivity values (e.g. rubyfish are relatively short-lived and fast growing compared with orange roughy), but it is widely recognized that these deep-sea species are less productive and more vulnerable to fishing pressure than shelf species (e.g. Gordon, 2005; Japp & Wilkinson, 2007; Sissenwine & Mace, 2007).

Deep-sea trawl fisheries occur on seamounts for a number of species. These include alfonsino (*Beryx splendens*), black cardinalfish (*Epigonus telescopus*), orange roughy (*Hoplostethus atlanticus*), southern boarfish (*Pseudopentaceros richardsoni*), macrourid rattails (primarily roundnose grenadier *Coryphaenoides rupestris*), oreos (several species of the family Oreosomatidae, including the smooth oreo *Pseudocyttus maculatus* and the black oreo *Allocyttus niger*), and toothfish (Patagonian toothfish *Dissostichus eleginoides* and Antarctic toothfish *D. mawsoni*) (Clark *et al*., 2007). Other fisheries occur over

Table 1. Bathymetric distribution and biological characteristics of commercial fish species on seamounts. Depth is the main commercial range. Data on maximum age, resilience (population doubling time), and intrinsic extinction vulnerability, the latter based on Cheung *et al*. (2005) and consisting of a relative measure ranging from 1 (very low) to 100 (very high), are from Fishbase.

Tabla 1. Distribución batimétrica y características biológicas de los peces comerciales capturados en montes submarinos. La profundidad se refiere a rangos en que se efectúan las pescas comerciales: edad máxima, productividad relativa (lapso en que se duplica la población) y vulnerabilidad intrínseca de extinción. De acuerdo a Cheung *et al.* (2005), una medida relativa varía de 1 (muy bajo) a 100 (muy alto), datos tomados de Fishbase.

Species	Scientific name	Main depth range (m)	Maximum age (years)	Resilience (years)	Intrinsic extinction vulnerability
Alfonsino	*Beryx splendens*	300-600	25	5-14	65
Cardinalfish	*Epigonus telescopus*	500-800	100	14	70
Rubyfish	*Plagiogeneion rubiginosum*	250-450	10	2-4	49
Blue ling	*Molva dypterygia*	250-500	20	5-14	73
Black scabbardfish	*Aphanopus carbo*	600-800	30	5-14	63
Sablefish	*Anoplopoma fimbria*	500-1,000	115	>14	76
Pink maomao	*Caprodon* spp.	300-450		2-4	50
Southern boarfish	*Pseudopentaceros richardsoni*	600-900		2-4	42
Pelagic armourhead	*Pseudopentaceros wheeleri*	250-600	11	7	57
Orange roughy	*Hoplostethus atlanticus*	600-1,200	150	>14	74
Oreos	*Pseudocyttus maculatus, Allocyttus niger*	600-1,200	100	>14	72
Bluenose	*Hyperoglyphe antarctica*	300-700	15	5-14	74
Redfish	*Sebastes* spp. (*S. marinus, S. mentella, S. proriger*)	400-800	75	>14	75
Roundnose grenadier	*Coryphaenoides rupestris*	800-1,000	54	5-14	78
Toothfish	*Dissostichus* spp.	500-1,500	20–30	5-14	86
Notothenid cods	*Notothenia* spp.	200-600	15-20	5-14	58

seamounts, such as those for pelagic species (mainly tunas), near-bottom fishing for mackerels, and target species for smaller scale line fisheries (e.g. black scabbardfish *Aphanopus carbo*) (FAO, 2004; da Silva & Pinho, 2007).

Many of the main commercial seamount species are widespread, especially through the Atlantic, Indian, and South Pacific oceans (Table 2). A number of Southern Hemisphere species are found in the North Atlantic, but do not extend into the North Pacific (e.g. orange roughy, oreos). Some species are more localised to the North Atlantic (e.g. roundnose grenadier, blue ling, *Sebastes mentella, S. marinus*), and sablefish occur only in the North Pacific.

Seamount fisheries

Global overview

Seamount fisheries have taken place, or currently occur, on a large number of seamounts throughout the worlds' oceans. These are prominent in the Pacific ocean, but also in the southern Indian ocean, the Mid-Atlantic Ridge in the north Atlantic, and off the African coast in the south Atlantic (Fig. 2).

The largest seamount trawl fisheries have occurred in the Pacific ocean (Koslow, 2007; Clark *et al*., 2007). In the 1960s to 1980s, large-scale fisheries for pelagic armourhead and alfonsino took place on the Hawaiian and Emperor seamount chains in the north

Table 2. Geographical distribution of commercial fish species (+ indicates occurrence in that ocean).

Tabla 2. Distribución geográfica de las especies comerciales (+ indica presencia en un océano particular).

Species	North Atlantic	South Atlantic	North Pacific	South Pacific	Indian Ocean	Southern Ocean
Alfonsino	+	+	+	+	+	
Cardinalfish	+	+		+	+	
Rubyfish		+		+	+	
Blue ling	+					
Black scabbardfish	+					
Sablefish			+			
Pink maomao			+	+		
Southern boarfish		+		+	+	
Pelagic armourhead			+			
Orange roughy	+	+		+	+	
Oreos		+		+	+	+
Bluenose		+		+	+	
Redfish	+		+			
Roundnose grenadier	+					
Toothfish		+		+	+	+
Notothenid cods		+		+	+	+

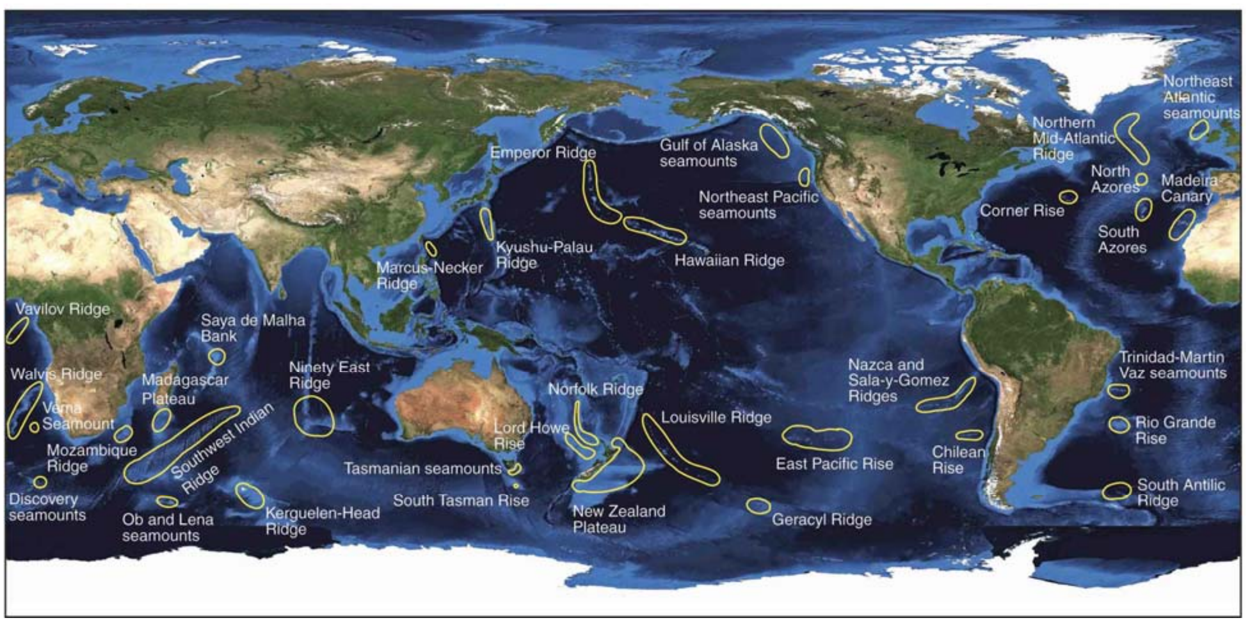

Figure 2. The distribution of major seamount/ridge fishing grounds (from Clark *et al*., 2007).

Figura 2. Principales montañas y cordilleras submarinas donde se realizan faenas de pesca comercial (tomado de Clark *et al*., 2007).

Pacific. In total, about 800,000 ton of pelagic armourhead and about 80,000 ton of alfonsino were taken. In the southwest Pacific, fisheries for orange roughy, oreos, and alfonsino were large and continue to be locally important. Orange roughy has also been the target of fisheries on seamounts off the central coast of Chile in the southeastern Pacific, on the Mid-Atlantic Ridge in the north Atlantic, off the west coast of southern Africa, and in the southwest Indian ocean. Roundnose grenadier was an important fishery for the Soviet Union in the North Atlantic, where catches were over 200,000 tonnes. Smaller fisheries for alfonsino, mackerel, and cardinalfish have occurred on various seamounts in the mid-Atlantic, southeast Pacific, and off the coast of north Africa. In the southern ocean, fisheries for toothfish, notothenids, and icefish can occur on seamounts as well as on slope and bank areas. Most of these seamounts are fished with bottom trawls, but several are also subjected to midwater trawl and longline fisheries.

In total, the international catch of the main commercial demersal fish species on seamounts by distant-water fishing fleets is estimated to be over 2.15 million tonnes of fish since 1968 (Table 3) (Clark *et al.*, 2007). Hence, seamount fisheries have contributed only a very small proportion of the total global wild-fish catch, which averaged about 60 million tonnes per year over the same period (Csirke, 2005).

South American fisheries

Most large volume deepwater fisheries have occurred in other regions, but several fisheries have developed off South America on seamounts. Off Brazil, a major programme of exploratory trawling between 2000 and 2006 covered a large part of the coast, although seamounts were of secondary importance in this work, which focused on the upper slope for finfish and shrimps (Perez *et al.*, 2009b). Seamounts of the Fernando de Noronha and Vitoria-Trinidade chains have been exploited, although mainly with longlines (Hazin *et al.*, 1998, Martins *et al.*, 2005) and only limited trawling for groupers (*Epinephelus* spp.) (Perez *et al*. 2009a). During the 1980s, trawlers from the then Soviet Union fished on the Vitoria-Trinidade and Martin Vaz seamount chains and developed a fishery for alfonsino on the Rio Grande Rise (Clark *et al*., 2007).

Table 3. Historic catches of the main fish species from seamounts, major fishing periods, and main gear types used in seamount fisheries (derived from data in Clark *et al*., 2007).

Tabla 3. Capturas históricas de las especies más relevantes capturadas en montes submarinos, periodo de pesca más importante y principal tipo de arte de pesca empleado en la pesquería (datos tomados de Clark *et al*., 2007).

Common name	Total historical catch (ton)	Main fishery years	Gear type
Alfonsino	166,950	1978-present	Bottom and midwater trawl, some longline
Orange roughy	419,100	1978-present	Bottom trawl
Oreos	145,150	1970-present	Bottom trawl
Cardinalfish	52,100	1978-present	Bottom (and midwater trawl)
Redfish	54,450	1996-present	Bottom and midwater trawl
Southern boarfish	9,600	1982-present	Bottom trawl
Pelagic armourhead	800,000	1968-1982	Bottom and midwater trawl
Mackerel species	148,200	1970-1995	(Bottom) and midwater trawl
Roundnose grenadier	217,000	1974-present	Bottom, and midwater trawl
Blue ling	10,000	1979-80	Bottom trawl
Scabbard fish	75,000	1973-2002	Bottom and midwater trawl
Sablefish	1,400	1995-present	(Bottom trawl), longline
Bluenose	2,500	1990-present	Bottom and midwater trawl
Rubyfish	1,500	1995-present	Bottom and midwater trawl
Pink maomao	2,000	1972-1976	Bottom and midwater trawl
Notothenid cods	36,250	1974-1991	Bottom trawl
Toothfish	12,250	1990-present	Bottom trawl, longline
Total	2,153,470		

In the southeastern Pacific, Soviet trawling occurred on the Nazca and Salas y Gomez Ridges for mackerel (*Trachurus murphyi*) and redbaits (*Emmelichthys* spp.), mainly in the 1970s but sporadic exploratory fishing also occurred in the 1980s (Clark *et al*., 2007; Gálvez, 2009). Off Chile, a commercial fishery for orange roughy and alfonsino developed on seamounts around the Juan Fernandez Archipelago in 1998 (Labbé & Arana, 2001, Guerrero & Arana, 2009). Orange roughy catches peaked at 1,870 ton in 2001, but declined thereafter (Paya *et al*., 2005). This fishery was closed except for a research quota in 2006 following decreasing catches and stock size estimates (Niklitschek *et al*., 2005, Sissenwine & Mace, 2007).

SUSTAINABILITY OF DEEPWATER SEAMOUNT FISHERIES

Deep-sea seamount fisheries, even within areas of national jurisdiction, have typically not maintained high catch levels over time. There are many examples of 'boom and bust' fisheries that developed and declined rapidly, sometimes within a few years or a decade (e.g. Uchida & Tagami, 1984; Koslow *et al*., 2000; Clark, 2001). Orange roughy is commonly cited as an example of this, as few of its fisheries in the world have proven to be sustainable (e.g. Branch, 2001; Clark, 2001; Lack *et al*., 2003; Sissenwine & Mace, 2007).

New Zealand fisheries have dominated global catches (Fig. 3), although note that this figure includes continental slope habitats as well as seamounts. The New Zealand fishery is really the only one that has persisted over time and much of this is due to fishing grounds in a restricted area of the Chatham Rise, to the east of the main New Zealand islands. Seamounts account for between 40 and 60% of the catch in New Zealand (Clark & O'Driscoll, 2003), even though serial depletion has occurred in some areas (Clark, 1999; Clark *et al*., 2000). The Australian fishery was very large for a number of years between 1989 and 1993, when high catch rates of spawning fish on St Helens seamount were regularly made, but the stocks were rapidly depleted and quotas were progressively reduced (Lack *et al*., 2003; Bax *et al*., 2005; Koslow, 2007). The St Helens fishery is now closed completely. A similar situation occurred in Namibia and Chile where, despite extensive research and precautionary management objectives, catches have not been sustained, and fisheries are now very small or just bycatch. The southwest Indian ocean is another area where large catches were taken for a short time, made worse by a total lack of any management on the High Seas, which saw an uncontrolled increase in effort in the early 2000s (from five vessels in 1999 to over 35 in 2000) and a sharp drop in catches and catch rates (FAO, 2002; Japp & James, 2005). Sissenwine & Mace (2007) described these catch histories as following two patterns: in the first, small stocks were fished down rapidly in only a few years before effective management could be implemented and, in the second, larger stocks were initially overestimated by research, and this was often coupled by non-conservative management practises and "fishing-down" phases, which lead to excessive depletion.

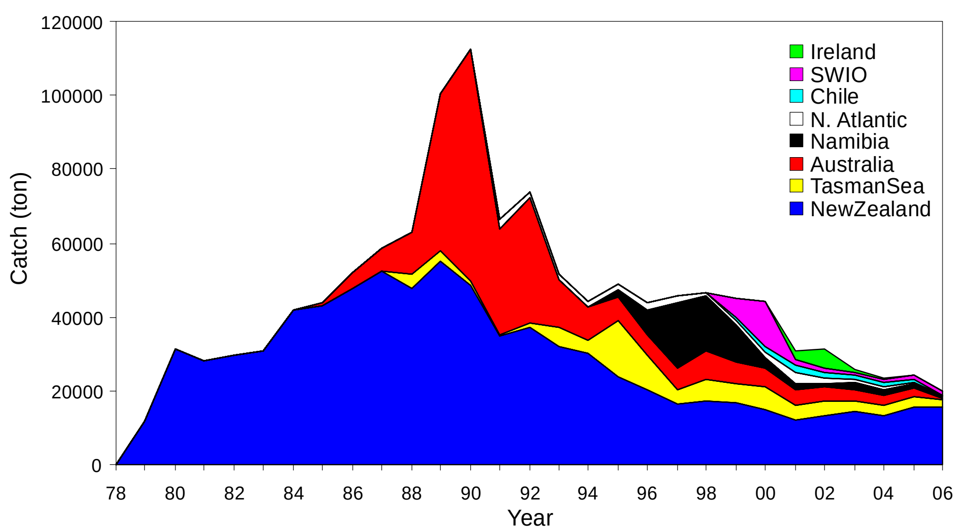

Figure 3. Estimated orange roughy catches for the main fishing areas around the world (compiled from various data sources).

Figura 3. Capturas estimadas de orange roughy extraídas en las principales áreas de pesca del mundo donde se distribuye esta especie (datos provenientes de diversas fuentes).

Orange roughy is one of the least productive commercial species, but is not necessarily an extreme example. Fisheries for other deep-sea species have also shown low resilience to large catches, such as the pelagic armourhead fishery off Hawaii in the 1970s, alfonsino in the north Atlantic, roundnose grenadier on the Mid-Atlantic Ridge, and deepwater notothenids in the southern ocean (Clark *et al*., 2007). These fisheries have sometimes maintained catches by moving to new grounds or by switching to other species as the target species biomass has declined (e.g. increase in alfonsino catches as pelagic armourhead was overfished on the Hawaiian seamounts (Clark *et al*., 2007)). However, even relatively shallow species (e.g. pink maomao, *Caprodon longimanus*) can be rapidly depleted over seamounts, evidenced by a short-lived fishery on the Lord Howe Rise, where Japanese catch rates in 1976 decreased from 1.7 to 0.2 ton h^{-1} over one year with a catch of not much more than 1000 ton (Sasaki, 1986). Sissenwine & Mace (2007) listed 44 deep-sea (> 200 m) area species combinations, 27 of which included stocks classed as overexploited or depleted. No stocks were identified as recovering.

Once overexploited, few deep-sea fisheries have shown signs of recovery. There are situations in which fishing success for orange roughy has improved with a reduction in effort levels, and fishers have reported increased catches of alfonsino and pelagic armourhead in some areas when the seamounts or fishing grounds have not been fished for a period. However, this may in part be related to fewer disturbances of aggregations with reduced trawling than an increase in stock size (Clark & Tracey, 1991). Orange roughy stocks in many areas generally continued to decline even when the catch has been reduced to levels thought by scientists to be sustainable. Some analyses have suggested depletion has not been excessive (Hilborn *et al*., 2006) but uncertainty about stock assessments and, in particular, assumptions about recruitment are critical in such evaluations. Irregular recruitment levels may be a key factor for the recovery of deep-sea species (Clark, 2001; Dunn, 2007).

The example of orange roughy fisheries, in particular, has given strong insights into three generic aspects that contribute to the lack of sustainability of deep-sea seamount fisheries:

Biological characteristics

Deep species often exhibit high longevity (up to 100 years for several species, e.g. redfish, orange roughy), late maturation (sometimes > 20 years before becoming mature, e.g. orange roughy, oreos), slow growth, low fecundity (e.g. deepwater sharks, orange roughy), intermittent recruitment (occurs with most species, but with long-lived species there could be decades between good year classes), and spawning may not occur every year (Morato *et al*., 2006; Morato & Clark, 2007). Intermittent spawning behaviour and the migration of aggregations to spawning grounds ("intermittent aggregation") have also been proposed to explain why some decreases in stock size appear to have been greater than expected based solely on the fisheries catch or why the levels of depletion have varied between different fishing grounds (e.g. Butterworth & Brandao, 2005). These types of fish generally have low rates of natural mortality and low production rates, meaning recovery is slow. Table 1 indicates that several of the major deepwater commercial fish species have a population doubling time ("resilience") of 14 years or greater (e.g. cardinalfish, orange roughy, redfish) and high vulnerability indices of 70 to 80. Their biology is not evolved to cope with high levels of natural predation and so they are more vulnerable to overfishing than shallow water shelf species.

Habitat/fishery type

Many species aggregate on seamounts or ridge peaks because of depth or oceanographic conditions (e.g. Koslow, 1997). Such aggregations will be more vulnerable to overfishing and rapid depletion than those in which species are more dispersed on shelf or slope habitats. When aggregations are formed for spawning, the effects may be greater because of the possible disruption of spawning processes and reduced reproductive success (although this has rarely been documented). Target trawling on seamounts is often localized, and the density of tows per seamount area can be high (e.g. O'Driscoll & Clark, 2005). Heavy bottom trawl gear is used to tow on the rough, hard bottom, which is often characteristic of seamounts, and the invertebrate fauna, often dominated by large, slow-growing, sessile organisms, are especially vulnerable to damage by fishing gear (e.g. Clark & Koslow, 2007). Fishing grounds often occur offshore and so are carried out by large powerful vessels with the ability to work large gear, catch and process large amounts of fish, and stay at sea for long periods.

Economic considerations can also be important. The market value of some of the deepwater species is high, which creates an incentive for commercial operators to target the species (Japp & Wilkinson, 2007). Good catches will offset the relatively high operating costs of vessels offshore and create pressure to continue fishing as stocks decline or if there are high costs associated with industry funding of research and management (e.g. Francis & Clark, 2005).

Research and management limitations Francis & Clark (2005) described issues affecting the sustainability of orange roughy based on the New Zealand experience. As well as a lack of knowledge of the biological characteristics and processes (mentioned above), they emphasised how standard stock assessment techniques were often difficult to apply in the deep-sea environment and given the aggregating nature of the species. Punt (2005) and Sissenwine & Mace (2007) also discussed difficulties for estimating the stock size of orange roughy and how uncertain such stock assessments are likely to be. This uncertainty in the science has, at times, led to subsequent management responses being too slow or insufficient (Bax *et al*., 2005; Francis & Clark, 2005). Precautionary management is required and the standard target reference levels and management concepts (e.g. MSY, fishing down practices) applied in several deep-sea fishing countries (e.g. New Zealand) have proven risky and insufficiently conservative (Sissenwine & Mace, 2007).

Management of seamount fisheries

The "ecosystem approach" to fisheries management is now widely advocated and applied in deep-sea fisheries (FAO, 2003). However, the inherent restrictions on obtaining sufficient stock assessment or benthic habitat data (compared with nearshore shelf/slope fisheries) mean that management regimes typically operate at a low level of knowledge, and management action must occur in a highly precautionary manner. There is an increasing body of literature on data, reporting requirements, and appropriate management actions to help ensure the sustainability of deep-sea fisheries (Francis & Clark, 2003; FAO, 2007, 2008; Sissenwine & Mace, 2007; Probert *et al.*, 2007; Morato & Pitcher, 2008; Rogers *et al*., 2008).

Various management actions now include closed seamounts, fishing method or gear restrictions, depth limits, individual seamount catch quotas, bycatch quotas, and habitat exclusion areas (e.g. hydrothermal vents) (Probert *et al*., 2007). Closed areas are a common method to protect the habitat, but can be problematic because they can exclude fishing from productive grounds. Recent initiatives by some fishing consortia (e.g. southwest Indian Ocean Fisher's Association, New Zealand Deepwater Group) have instigated "Benthic Protected Areas (BPAs)" which the fishers voluntarily avoid to prevent seafloor damage by bottom trawling. Industrial "buy-in" to environmental protection is a positive step as long as science is involved to help design the BPA distribution and size so they are representative and effective. Typically, the fine spatial scale needed to research and manage seamount stocks is problematic. Serial depletion of fish stocks can occur quickly (Clark, 1999), yet catch rates can be maintained even though biomass is being reduced (Clark, 2001; Lack *et al*., 2003; Francis & Clark, 2005; Sissenwine & Mace, 2007). There is no easy answer to setting appropriate precautionary catch limits for new seamount fisheries, although restricting effort to only a few vessels (e.g. Namibian orange roughy fisheries; Boyer *et al*., 2001) and imposing limits on the catch from a single seamount or feature (e.g. New Zealand; Rogers *et al*., 2008) can help reduce the risk of rapid over-exploitation. An analysis of seamount catch over time indicates that the initial orange roughy biomass on a single seamount feature may generally be only a few thousand tonnes (Clark *et al*., 2001).

Effects of bottom trawling on the wider benthic community and habitat also need to be considered (e.g. Dayton *et al*., 1995; Hall, 1999; Clark & Koslow, 2007). The deep-sea fish community includes species that have low productivity and can be vulnerable to the effects of fishing, even if the fishery targets a different species. Seamounts can host endemic species or species with a very restricted geographical distribution (Rogers, 1994; Richer de Forges *et al*., 2000), as well as habitat-forming fauna such as deep-sea corals and sponges that are regarded as indicators of "vulnerable marine ecosystems" (FAO, 2008). This has been part of the justification for calls from NGOs in recent years for a moratorium on bottom trawling on the High Seas. Management, therefore, needs to balance exploitation and conservation, both of fisheries and seamount habitats (Probert *et al*., 2007). A mixture of protected and open seamounts is one strategy that appears to be successful off New Zealand (Brodie & Clark, 2003).

Future prospects

Seamount fisheries for deep-sea species in the future are likely to be small volume, high value fisheries. The track record of the deeper species such as orange roughy and oreos indicates that large catches will only last a few years, and highly precautionary catch limits may be needed if they are to be sustainable. More productive seamount species such as alfonsino, scabbardfish, grenadier, and armourheads are more resilient to heavy fishing and have been classified as less vulnerable (Gordon, 2005), but stocks appear to be variable and are still unlikely to withstand high catch levels for more than a few years. Where estimates have been made, the biomass of many fish stocks on seamounts is relatively low and does not exceed several hundreds of thousands of tonnes for even the most abundant species (e.g. Sasaki, 1986; Vinnichenko, 1998, 2002b). An analysis of New Zealand seamount fisheries for orange roughy suggests that few seamounts can support long-term catches of more than a few hundred tonnes per year (Clark *et al.*, 2001).

Japp & Wilkinson (2007) and Sissenwine & Mace (2007) have both summarized "deep-sea" catches as reported in FAO statistics up to 2005. The catch trends for the main seamount species or family groupings typically show a decline after an initial rapid increase as the fisheries developed. Although FAO statistics cover very large regions of the world and do not distinguish seamounts from slope fisheries, these patterns are consistent with those estimated from specific seamount data by Clark *et al*. (2007).

Clark *et al*. (2007) summarized the global status of the large offshore seamount fisheries. Their conclusions were that intense fishery pressure on the seamounts of the Corner Rise, north Azores area of the Mid-Atlantic Ridge, and the Vavilov, Walvis, southwest Indian, Emperor and Hawaiian ridges has resulted in the depression of many fish stocks, with no increase of catch in these areas likely within the next few years. Relatively new fishing grounds such as seamounts on the Norfolk, Lord Howe, Louisville, and south Tasman Rise have been targeted for deepwater species such as orange roughy and are also fully exploited. Some areas of the northern Mid-Atlantic Ridge and some offshore seamounts located in Antarctic waters and the central oceanic regions may have some potential for further exploitation. However, the volume of deep-sea species is likely to be small and short-lived if fisheries are not managed carefully. Such management will also need, in the future, to take account of balancing fisheries management with conservation of the benthic environment.

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