MANAGING BIODIVERSITY: Invertebrate By-catch in Seamount Fisheries in the New Zealand Exclusive Economic Zone[1]

By:

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Abstract

New Zealand introduced an individual transferable quota (ITQ) fisheries management system in 1986, with total allowable catches (TACs) applied to individual fish stocks. While generally recognised as successful there has been serial depletion and stock collapse of the major deepwater species orange roughy *Hoplostethus atlanticus* within 20 years of first exploitation. Currently around 70% of the orange roughy catch comes from trawling on seamounts. The invertebrate fauna of seamounts are not well described, but trawling is likely to have a major impact on the large slow-growing epibenthic organisms. An incremental strategy to address the impacts of trawling on seamounts was developed by the Ministry of Fisheries. Nineteen seamounts (out of 800) have been closed to fishing. Research and monitoring will be necessary to measure the impact of and recovery from trawling on seamounts.

Introduction to Seamount Fisheries

Fisheries have developed for teleosts and crustacea on and around seamounts in the Pacific Ocean along the southern Emperor and northern Hawaiian Ridge in the North Pacific (Uchida and Tagami 1984; Sasaki 1986; Wilson and Seki 1994), and in the southwest Pacific Ocean around New Zealand, New Caledonia and Tasmania (Lehodey *et al.* 1994; Koslow, 1997; Annala *et al.* 2000). In the past decade fisheries have expanded for toothfish around sub Antarctic islands and seamounts in the Southern Ocean (ISOFISH 1998).

Seamounts, steep sided undersea mountains, are widely distributed in the world's oceans and usually associated with volcanic activity (Epp and Smoot 1989; Rogers 1994). Strict definitions describe seamounts as features with an elevation greater than 1000m, but in practice seamount is applied to knolls (elevation 500-1000m) and hills (elevation <500m) that contrast with the surrounding seafloor (Rogers 1994). Seamounts often occur in clusters along ridges leading to island groups or chains that are physically isolated from other island chains. In the New Zealand context seamounts have been defined as "identifiable geological/topographical features that rise greater than 100 metres above the surrounding sea floor in any depth of water, whether they are stand-alone features or part of a range" (Strategy 1999).

Seamounts and oceanic islands enhance productivity, due to Taylor columns upwelling nutrient rich water, and the trapping of diurnally migrating plankton (Rogers 1994), and provide a unique deep-sea environment for fishes and invertebrates that are not found in the open ocean (Boehlert and Mundy 1993; Koslow 1997; de Forges *et al.* 2000). Several teleosts spawn above seamounts and form dense seasonal aggregations. The same species are characterized by slow growth rate and late age at maturity (Tracey and Horn 1999). This combination of high density and longevity makes seamount species vulnerable to exploitation. The wide distribution of seamounts further increases the risk of overexploitation through unregulated fishing in high seas fisheries, as occurred with the armorhead *Pseudopentaceros wheeleri* during the 1970s (Somerton and Kikkawa 1992) and currently with orange roughy *Hoplostethus atlanticus* in the Indian Ocean.

The stock relationships among the isolated seamount fisheries are not well described. Genetic studies suggest an ocean wide population structure for target species such as the armorhead *P. wheeleri* (Martin *et al.* 1992), alfonsino *Beryx splendens* (Hoarau and Borsa 1999), wreckfish *Polyprion americanus* (Sedberry *et al.*1996; Ball *et al.* 000), and oreos *Pseudocyttus maculatus* and *Allocytus niger* (Ward *et al.* 1996; Smith *et al.* 2000), with extensive dispersal through the pelagic larval and juvenile stages. Indeed lack of genetic differences between the pelagic morphs of the armorheads *P. wheeleri* and *P. pectoralis* lead to the conclusion that the armorhead consists of a single metamorphic species (Humphreys *et al.* 1989). In contrast genetic differentiation has been reported among populations of the orange roughy *H. atlanticus* (Smolenski *et al.* 1993; Smith *et al.* 1997) and the toothfish *Dissostichus eleginoides* (Smith and McVeagh 2000).

There is a growing management focus on the effects of fishing on non-target species and on habitats (eg Hall 1999; Kaiser and de Groot 2000). Trawling has been likened to forest clearcutting and poses a major threat to biodiversity and the sustainability of benthic communities (Wattling and Norse 1998). Negative impacts of trawling on the seabed are widely reported, but for the most part are limited to shallow water communities (Wattling and Norse 1998; Hall 1999; Kaiser and de Groot 2000). It is likely that the effects of trawling will be more severe in deepwater communities, due to the lower productivity of the environment, the longevity of many species, and the high level of endemism (Rogers 1994; Koslow 1997).

Deepwater Seamount Fisheries in the New Zealand EEZ

New Zealand lies in the southern Pacific Ocean, 2000 kilometres east of Australia. The New Zealand Exclusive Economic Zone (EEZ) covers approximately 4.0 x 10^6 km^2 over 30^olatitude, ranging from the subtropical Kermadec Islands to the subantarctic Auckland and Campbell Islands (Figure 1). The New Zealand EEZ accounts for about 1% of the world's catch, with seafood exports worth NZ$1.43 billion in 2000. The seafood industry, which includes fisheries and aquaculture, is the 4th largest export earner in New Zealand after the dairy, meat and forestry industries, and is expected to grow to NZ$2 billion by 2010, through adding value to products rather than expanding fisheries.

Around 70% of the EEZ is deepwater >1000m; approximately 800 seamounts have been identified, although most are unexplored. Deepwater fisheries developed during the 1980s and the slope edge and seamounts are the focus of trawl fisheries for orange roughy *H. atlanticus*, black oreo *A. niger*, and smooth oreo *P. maculatus* at depths of 600-1200m. Black cardinalfish *Epigonus telescopus* and ribaldo *Mora mora* are taken as by-catch, and are increasingly the target of local fisheries. Alfonsino *Beryx splendens* are caught in mid-water trawls over shallower seamounts and on the slope edge between 300-500m, where rubyfish *Plagiogenion rubiginosum* are taken as by-catch.

Orange roughy have a wide distribution in the Atlantic, Indian and South Pacific Oceans. In spite of the extensive distribution adults are not highly migratory and movement, inferred from seasonal catches and changes in distribution, is only 100s of kms (Francis and Clark 1998). Orange roughy eggs hatch near the bottom and the juveniles are assumed to be demersal (Zeldis *et al.* 1994) reducing the potential for extensive gene flow. The species is slow-growing, reaching maturity at 20-30 years of age, and may live for more than 100 years (Fenton *et al.* 1991; Tracey and Horn 1999).

The orange roughy fishery expanded during the 1980s, with catches reaching 50 000 tonnes in 1988/89, and then declined due to quota restrictions. Initially most fish were caught during the spawning season on the Chatham Rise in the Pacific Ocean to the east of New Zealand and on the Challenger Plateau in the Tasman Sea to the west of New Zealand (Figure 1). Orange roughy account for around two thirds of the export returns from deepwater fisheries with a value of $NZ84 million in 2000.

There are several geographically isolated spawning populations of orange roughy, which are the major targets of fishing within the EEZ. The fisheries initially concentrated on flat bottom and slope edge, but technical developments, such as GPS navigation, net monitoring, and swathe mapping, coupled with increasing experience in the deepwater fisheries lead to the targeting of orange roughy concentrations on seamounts. Currently around 70% of the annual catch is taken on seamounts (Clark 1999).

Two species of oreo, *A. niger* and *P. maculatus*, support fisheries in the New Zealand and Australian EEZs. In the New Zealand EEZ black and smooth oreo, together with the less abundant spiky oreo *Neocyttus rhomboidalis*, have been managed under a combined quota. The proportion of oreo catch derived from seamount fisheries increased from around 20% in the 1980s to 65% in the 1990s (McMillan *et al.* 1996).

Spawning occurs from October to December and is widespread on the Chatham Rise. Both species are long lived with estimated maximum ages of 86 years for *P. maculatus* and 150 years for *A. niger* (Doonan *et al.* 1995b). Smooth oreo adults are generally found north of 52^{o}S, but most of the few recorded juveniles have been found between 60-68^{o}S (James *et al.* 1988); only 23 black oreo juveniles have been recorded from the New Zealand EEZ (McMillan, NIWA, unpub.obs.). Juveniles of both species appear to be pelagic based on their coloration and relatively small eye size (James *et al.* 1988; McMillan unpub. obs). The pelagic features, coupled with low $\Delta^{14}C$ levels, suggest a high latitude origin for black and smooth oreo juveniles (Morison *et al.*1999). It is possible that there is 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.

Black cardinalfish *E. telescopus* are widely distributed in the North Atlantic from Iceland to the Canary Islands, in the western Mediterranean, and in the South Atlantic, Indian, and southwest Pacific Oceans (Abramov 1992). The species occurs between 200–1400 m but is most common between 600–900 m, overlapping the upper end of the depth range for orange roughy and the lower end for alfonsino in New Zealand waters. The juveniles are pelagic and undergo major ontogenetic changes; little is known of adult movements (Mayer 1974). Around half the New Zealand catch (c2 000 t per annum) has been taken as by-catch, with 80% taken in the orange roughy fisheries (Smith and Paul 2000). Alfonsino *Beryx splendens* have a wide distribution in tropical and temperate waters of the Atlantic, Indian and Pacific Oceans (Kotylar 1996), where they occur over seamounts and the continental slope in depths between 25–1200m, but are most abundant between 300–500m. In the South Pacific Ocean there are fisheries off New Caledonia (Lehodey *et al.* 1997) and in the New Zealand EEZ (c2700 t per annum). The adults do not appear to make extensive adult migration to spawning areas (Masuzawa *et al.* 1975; Alekseev *et al.* 1986; Lehodey *et al.* 1997), but the larvae and juveniles disperse widely in the pelagic environment for several months before settling on shallow seamounts (Mundy 1990; Boehlert and Mundy 1992).

Management History of Deepwater Fisheries in New Zealand

Deepwater fisheries were developed by foreign vessels during the 1970s when total catches reached a peak of 500 000 t per annum. In 1978 New Zealand extended its management jurisdiction from 12 to 200 miles and domestic companies began to take over deepwater fishing, initially through joint ventures with overseas companies. A Deepwater Enterprise Allocation was established in 1983 to allocate deepwater quotas to New Zealand companies and to encourage development of the fisheries. This system was the forerunner of the Individual Transferable Quota (ITQ) management system, which was introduced in October 1986 for coastal and deepwater fisheries.

ITQs provide individuals with a transferable or tradeable right to harvest a specific proportion of the total allocated surplus production of a stock. The history and development of ITQ systems in general have been summarised in Munro and Pitcher (1996). ITQ systems were initially adopted by small isolated states such as Iceland (Arnason 1996) and New Zealand (Annala 1996) to shift management from ad hoc input controls to a universal output control system, based on a Total Allowable Catch (TAC) for each species or groups of species. The successes and problems of the ITQ system in New Zealand have been reviewed by Crothers 1988; Dewes 1989, 1998; Davies 1992; Sissenwine and Mace 1992; Clark 1993; and Annala 1996.

The quota management system (QMS) was introduced with two broad goals: conservation, to limit catches to levels that maximise production; and allocation, to maximise the net economic return to the nation (Crothers 1988). The New Zealand Ministry of Fisheries sets an annual TAC, or Total Allowable Commercial Catch (TACC), for each species in the QMS, based on stock assessments produced by fishery working groups made up of representatives from the seafood industry, government agencies, and non-government organizations. The stock assessment process is the core system providing advice to the Minister of Fisheries for setting and adjusting quotas. At the time of introduction there were 26 species, or species groups, in the QMS. There are now 50 species groups in the QMS, which include most major fisheries within New Zealand's EEZ, and will eventually include all commercially harvested species.

New Zealand introduced a comprehensive ITQ system with mechanisms to deal with allocation, monitoring, and enforcement. While generally recognised as successful by both industry and managers, there were problems with the initial ITQ system, which have been identified, and for the most part have been amended (Dewes 1989, 1998; Annala 1996). Specific issues that have impacted on the deepwater fisheries have been:

Stock assessment

At the time of the introduction of the ITQ system there were limited skills and facilities for undertaking stock assessments in New Zealand (Sissenwine and Mace 1992). The skill base has been expanded substantially and a dedicated deepwater research vessel built. Under science reforms carried out in the early 1990s the provision of stock assessment advice has been transferred into crown research institutes and separated from policy development in a new Ministry of Fisheries.

Definition of ITQs

The initial definition of ITQs defined quotas as fixed quantities and created problems for the substantial reductions in orange roughy quota in the late 1980s (Sissenwine and Mace 1992). In October 1990 ITQs were re defined as portions of the annual TACs, with no requirement for government to compensate quota holders for quota reductions (Annala 1996).

Productivity

Orange roughy are much less productive than initially believed (Mace *et al.* 1990), and quotas have been revised downwards (Table 1), with severe reductions, in the past 2 years. Needless to say quota reductions continue to meet with strong opposition from the industry.

Management areas

Broad area TACs are not appropriate for individual seamount management (Clark 1999), and can lead to serial depletion as individual seamounts are overfished within a management area. Individual feature management is being used for orange roughy on the eastern Chatham Rise and in northern New Zealand, but there is a trade off against practicalities of assessment and enforcement (Clark 1999).

Summary of Status and Trends of Target Species

Orange roughy

There are five main orange roughy fisheries (Figure 2), which are treated separately for stock assessment purposes (Annala *et al.* 2000). The main fisheries are: the Chatham Rise, Puysegur, and southern area (management area ORH 3B), the Challenger Plateau (ORH 7A), east coast (ORH 2A, 2B, 3A), west coast South Island (ORH 7B), and northern North Island (ORH 1). The Chatham Rise is the largest fishery and the east coast the second largest fishery. Landings and TACs for the combined fishstocks peaked at 50 898 t and 62 474 t, respectively, in 1988-89. The TACs have since been reduced (Table 1) as stock assessment results have indicated that previous catch levels were not sustainable (Annala *et al.* 2000). The combined TACs totalled 20 345 t in 1998-99 (Table 1), but there have been major reductions in the 2000-2001 fishing year for three of the fisheries, which have produced just under 34% of the total catch. The TAC for the Challenger Plateau fishery (ORH 7A, Table

1), which is at only 3% of virgin biomass (Annala *et al.* 2000), has been reduced from 1425 to 1 t, effectively closing the fishery.

There have been changes in the orange roughy fisheries, as new grounds have been discovered. In the east coast fishery there was a shift in effort from the spawning area on Ritchie Bank (ORH 2A) to seamounts off East Cape (Figure 2) in 1993/94. The Minister of Fisheries agreed with industry to manage the East Cape fishery as a separate stock (ORH 2A north) from the mid-east coast stock (ORH 2A south, 2B, 3A), which includes the Ritchie spawning stock (ORH 2A South) (Annala *et al.* 2000). The TAC for the East Cape fishery, which is at 14% of virgin biomass (Annala *et al.* 2000), has been reduced from 2500 to 200 t, and for the mid-east coast fishery, which is at 10% of virgin biomass (Annala *et al.* 2000), the TAC has been cut from 2100 to 1500 t for 2000-2001, with a further cut to 800 t for the 2001-2002 fishing year.

High catches on the Chatham Rise during the late 1980s and 1990s were in part maintained by the discovery and development of new seamount fisheries on the eastern and southern Rise, leading to serial depletion of seamount complexes (Clark 1999; Annala *et al.* 2000). The catch distribution within ORH 3B (Table 1) has been influenced by a series of catch-limit agreements between the Minister of Fisheries and industry, which have changed from year to year. During the 1990s more than 50% of the catch has come from 4 seamount complexes on the eastern and northwest Chatham Rise and all have shown a decline in catch rate. The TAC was reduced from 21 300 t to 12 700 t in 1995-96 and further reduced to 7 200 t in 2000-01.

Localised fisheries developed on seamounts in the south of ORH 3B in the early 1990s, but have been shortlived as catches rapidly decreased. The Puysegur fishery developed in 1990-91, but catch limits were undercaught from 1993-94 and the fishery was voluntary closed by industry in 1997-98.

Fisheries were developed in ORH 1 in the mid 1990s, and the area has been subject to an adaptive management programme with a catch limit of 1000 t applied to a seamount complex in the western Bay of Plenty in 1995-96 (Annala *et al.* 2000). An additional 800 t was allocated for exploratory fishing in 1996-97 in designated areas, but with catch limits on individual seamounts (Annala *et al.* 2000).

Additional orange roughy fisheries have been developed outside the EEZ on the Louisville Ridge to the east of New Zealand, on the Lord Howe Rise in the Tasman Sea, and on the South Tasman Rise outside the Australian EEZ. In all fisheries catches have declined rapidly within a few years of exploitation.

Oreos

The oreo fisheries have been divided into five management areas (Figure 2). The main fisheries are on the Chatham Rise (OEO 3A and OEO 4); these fisheries started in the early 1970s with catches by Soviet vessels and reached a peak of about 26 000 t in 1981 (Table 1). Subsequently other oreo fisheries developed off the south east coast of the South Island, to the south of New Zealand on the Puysegur/Macquarie Ridge (OEO 1), and on the Pukaki and

Bounty slopes (OEO 6). There are two fisheries on the Chatham Rise, separated by about 100 nautical miles (Doonan *et al.* 1995a). The western fishery (OEO 3A) is a target fishery for black and smooth oreo which are caught in approximately equal quantities, with a minor by-catch of orange roughy. The eastern fishery (OEO 4) is a target fishery for orange roughy with a by-catch of black and smooth oreo, the latter in much smaller quantities.

The annual catches and TACs for the combined oreo species by fishing area are shown in Table 2. The total oreo catch from OEO 4 (western Chatham Rise) exceeded the TAC in 1991–92 to 1994–95 and has remained high, while the orange roughy fishery has declined. In area OEO 3A the TAC was reduced from 10 106 to 6 600 t in 1996–97, to 5900 t in 1999–00, and to 4400 t for 2000-01, with a voluntary agreement to limit smooth oreo catch to 1300 t.

The oreo catch from the Subantarctic area (OEO 6) increased substantially in 1994–95 and exceeded the TAC in 1995–96. The OEO 6 TAC was increased from 3000 to 6000 t in 1996–97. OEO 1 was fished under an adaptive management programme up to 1997–98, and then the TAC reverted back to the 1991-92 levels, but with a voluntary agreement not to fish for oreos in the Puysegur area, because this area had been voluntary closed to orange roughy fishing.

Importance of Biodiversity in Seamount Fisheries

Many of the commercially important seamount fishes have ocean wide distributions (Rogers 1994), but a high degree of endemism of both invertebrates and small benthic fishes has been reported among seamounts (Wilson and Kaufmann 1987; de Forges *et al.* 2000). The wide, but discontinuous distribution of seamounts, creates unique problems for the dispersal and recruitment of fishes and invertebrates, with potential loss of larvae and juveniles from the local environment (Boehlert and Mundy 1993). Different species have evolved different strategies for dispersal from and recruitment to seamount environments (Parker and Tunnicliffe 1994). Even amongst the commercially important teleosts some species, such as armorhead, alfonsino, and oreo, have extensive ocean wide pelagic juvenile dispersal and recruit to distant sea mounts, while orange roughy have limited dispersal with a short larval stage and assumed benthic juveniles (Zeldis *et al.* 1994). These different dispersal patterns are reflected in levels of genetic differentiation with low differentiation in oreo (Ward *et al.* 1996; Smith *et al.* 2000) and higher differentiation in orange roughy (Smolenski *et al.* 1993; Smith *et al.* 1997). Species with narrow dispersal capabilities will be more vulnerable to localised depletion.

Orange roughy are the dominant species in most deepwater fisheries in the New Zealand EEZ, apart from the southern Chatham Rise where oreos dominate. However small numbers of a large range of species have been recorded from seamount fisheries with 29 species of elasmobranch and 139 teleosts (Clark *et al.* 1999). Many of these species do not appear to be restricted to seamounts and the impacts of fishing on biomass is unknown.

Fish species adapted for seamounts have some unique characteristics. Orange roughy have a high metabolic rate and protein content, more typical of shallow water species than bathypelagic species at similar depth ranges, and are an exception to the general rule of declining metabolism with depth (Koslow 1997). Orange roughy form dense aggregates, and the density around sea mounts may be an order of magnitude greater than density of all other fish species dispersed over the sea floor (Koslow 1997). Regime shifts in pelagic and shallow demersal fish communities are known to occur over decades (Steele 1998). There are few long-term data sets for seamount fishes, but the longevity and unique ecological characters of the dominant teleosts would argue against short-term shifts in abundance and species composition.

Unlike shallow, soft-sediment communities in the North Sea, where benthic organisms are part of the direct fish food chain, the epibenthic invertebrates and commercial fishes occupying seamounts are not directly linked in a food chain, although they utilise the same physical environment. It is possible that epibenthic communities on seamounts provide nursery habitat for some juvenile fishes, although this does not appear to be the case for orange roughy (Koslow and Gowlett-Holmes 1998). Orange roughy and other seamount teleosts are part of a surface down food web, driven by sedimentation and vertical migration, both daily and seasonal, and through horizontal advection (Koslow 1997).

The macro invertebrates on seamounts are dominated by suspension feeders, such as corals, which require a hard substrate and enhanced water flow (Wilson and Kaufman 1987; Rogers 1994). The deepwater black corals (antipatharians) and horny corals (gorgonians) are most abundant near the peaks of seamounts where the mean water speed is greatest (Genin *et al.* 1986). Deepwater corals, and other suspension feeders, show a negative correlation with sedimentation and depth from the seamount summit (Genin *et al.* 1986; Grigg *et al.* 1987). Large corals provide habitat for a diverse facultative fauna, for example 18.5 kg of the deepwater bank-forming coral *Lophelia pertusa*, from around the Faroe Islands, harboured 256 species (Jensen and Frederiksen 1992). Active volcanic seamounts and seeps also harbour very specialised vent fauna, dominated by polychaetes and molluscs (e.g. Vrijenhoek 1997).

Non-target Biodiversity Concerns

The main concerns for seamount invertebrates are the same as for shallow water ecosystems: Can populations sustain the current levels of disturbance or will populations suffer declines, or even extinctions? (Kaiser and de Groot 2000). While there are few data on the impacts of trawling in deepwater environments (Koslow and Gowlett-Holmes 1998) the indications are that impacts will be more severe and longer term than in coastal waters, and that once depleted seamount species may take decades, or even centuries, to regenerate (Koslow 1997). Seamount topographies, along with navigation technology, lead to a large number of trawl tows over a relatively small area, and with the heavy trawl gear used in the fisheries, produces intense local disturbances.

The impact of trawling in shallow communities has two effects on benthic organisms, direct damage through ploughing and scraping, and indirect effects of attracting predators and scavengers. Trawling has lead to a reduction in the abundance and number of benthic species in the Irish Sea (Kaiser and Spencer 1996). Deepwater communities are less adapted to disturbance, for example from storm events, than shallow communities. The large epibenthic organisms are likely to be the most vulnerable to trawling and these provide structure for many facultative species. There is anecdotal evidence for reduction in invertebrate by-catch in orange roughy trawls in the New Zealand fisheries (Jones 1992). This has been confirmed in a comparison of the catch composition of corals in 6 trawls from unfished seamounts (total coral catch 3000 kg) with 13 trawls (5 kg coral) on fished seamounts on the northwest Chatham Rise (Clark *et al.* 1999). On Tasmanian seamounts Koslow and Gowlett-Holmes (1998) recorded major impacts on biodiversity within a few years of the development of the orange roughy fishery. On heavily fished seamounts(>1000 trawls) reef aggregate had been removed or reduced to rubble, the invertebrate biomass was 83% lower, and the number of species 59% lower, than on lightly fished seamounts (10-100 trawls).

Concerns about loss of biodiversity are amplified when there is limited information on the taxonomy and biology of the seamount invertebrates. Key information gaps for seamount invertebrates are:

Endemism

Seamounts are colonised by a unique fauna that is distinct from that found on surrounding flat areas of seafloor (Wilson and Kaufman 1987; Rogers 1994; Probert *et al.* 1997). Recent surveys of seamounts suggest that there is a high level of endemism among seamounts in the Tasman Sea and southeast Coral Sea (de Forges *et al.* 2000). More than 30 species have been identified as endemic to seamounts, both individual seamounts and more general, in the New Zealand EEZ. Many of these endemic species are antipatharians and gorgonian corals (Clark *et al.* 2000). However the apparent high level of endemism has to be tempered against limited collections and poorly known systematics (de Forges *et al.* 2000). Endemism is intimately related to dispersal mechanisms, which also are poorly known for most seamount invertebrates.

Genetic diversity, reproductive biology and dispersal

In shallow water invertebrates genetic differentiation is correlated with larval dispersal (e.g. Burton 1983, Parsons 1996). The reproductive strategies and life-histories of many deepwater invertebrates are unknown, but some deepwater invertebrates show significant genetic differentiation. The deepwater (1000-3000m) bivalve *Deminucula atacellana* shows strong population genetic differentiation over small (150 km) spatial scales (Chase *et al.* 1998). The deepwater amphipod *Eurythenes gryllus* shows genetic differentiation among basin and seamount populations in the central North Pacific (Bucklin *et al.* 1987). In contrast the specialised vent communities are dominated by species with high dispersal potential and which exhibit little spatial genetic differentiation (Vrijenhoek 1997). Vent mussels *Bathymodiolus* sp have recently been discovered on a seamount in north east New Zealand, but the genetic relationships with species and populations in the western Pacific are unknown (Moraga *et al.* 1994).

Vegetative reproduction is common in some benthic invertebrates. Shallow water gorgonian corals can form dense colonies through clonal propagation, and disturbance enhances the generation of vegetative propagules (Coffroth and Lasker 1998). The impacts of clonal propagation are not widely considered in evolutionary models, but lead to small effective population sizes and low genetic diversity (Hughes *et al.* 1992).

Sampling scale and species identity

Much of the knowledge of seamount fauna is derived from by-catch in trawl fisheries (Probert *et al.* 1997; Koslow and Gowlett-Holmes 1998). Invertebrates in trawl samples are dominated by large epibenthic Cnidaria (black corals, true corals, and sea fans), Echinodermata (starfish, sea lilies, and brittlestarfish), Arthropoda (stone crabs and true crabs), and Mollusca (gastropods, octopus and squid), while limited dredge sampling from research vessels has revealed a different suite of small invertebrates (O'Shea, NIWA, pers. com.). Perspectives on the faunal composition of seamounts may change as more research sampling is carried out.

Probert *et al.* (1997) compared benthic invertebrate bycatch from 73 orange roughy trawl tows on the Chatham Rise, 49 tows on flat seabed and 24 from seamounts. They identified 96 species, but could not assign scientific names to most of them. The seamounts and flat areas were characterised by different invertebrate groups, with Gorgonancea and Scleractinia (corals) on seamounts and Holothuoidea, Asteroidea and Natantia on flat areas (Probert *et al.* 1997). The largest biomass was corals on seamounts.

Preliminary analyses of seamount fauna derived from trawl sites throughout the EEZ suggest that macrofauna on seamounts also occur on hard substrates on flat areas of seabed and many species are associated with substrate rather than topography (O'Shea NIWA, pers. com.). Many species are new records for science or for the New Zealand EEZ or simply new distribution records within the EEZ, due to the limited sampling to date. However some species appear endemic to seamounts, in particular black corals and associated fauna; surprisingly macrofauna from the northwest appear more similar to faunas in the southern than in the central EEZ (Clark *et al.* 1999).

Longevity

The ages and growth rates of many deepwater invertebrates are unknown but longevity and dispersal, are key factors influencing recovery from trawling impacts. The abundant coral *Lophelia pertusa* with colonies 1.5 m high in the North Atlantic maybe 200-366 years old (Wilson 1979). Colonies of the shallow water black coral *Antipathes fiordensis*, up to 4 m tall, are estimated to be >300 years old (Grange and Goldberg 1993). On deeper seamounts growth rates are likely to be slower and large colonies of the gorgonian coral *Paragorgia ?arborea* up to 10 m tall, and the black coral *Bathypathes platycaulus* up to 4-5 m tall, have been reported in the EEZ.

Incorporating Biodiversity in Management of Seamount Fisheries

Incorporating biodiversity into fishery management plans has not been easy, from both scientific and management perspectives, worldwide (Schalk 1998; Hanna 1999). In New

Zealand, fisheries management has been focused on single species, but with an established ITQ system, and the growing global emphasis on environmental management, the focus has broadened to include non-target species.

The Ministry of Fisheries developed a draft strategy to manage the adverse effects of commercial fishing on seamounts (Strategy 1999). The strategy has been developed with very limited information on the biology and distribution of invertebrates on seamounts and the impact of trawling on these communities. For this reason the strategy is incremental and will be re-evaluated as more data become available.

The strategy adopted a broad definition of seamount, and proposed managing a representative sample of seamounts throughout the EEZ from sub tropical to subantarctic water masses (Figure 1). Criteria were developed for the identification and selection of appropriate seamounts for management, based on guidelines developed by ANZECC (1998). The identification criteria are based on scientific information on physical and biological data:

- Representative - of seamounts and their fauna within a defined area.
- Comprehensive – covers the range of seamount ecosystems within a defined area.
- Ecological importance and uniqueness- species endemic to specific seamounts or to New Zealand; habitat/features on which species are dependent.
- Productivity – high productivity seamounts may support greater diversity.
- Vulnerability - susceptibility to natural or human induced change.
- Naturalness – extent to which subject to human change.

Additional criteria were used to select specific seamounts for management, based on social, cultural, and economic factors:

- Social interests – existing value.
- Scientific interests – potential value for research or monitoring.
- Economic interests – existing fishing activities.
- Practicality of management – isolated from other impacts, such as mining or drilling, or plate tectonics; acceptable to stakeholders and compatible with existing management measures.
- Customary interests – currently there are records of traditional fishing on deepwater seamounts.

Once key seamounts have been identified there is a limited range of options for reducing the impact of bottom trawling; options range from sub area and/or depth restrictions on specific seamounts, restricting fishing within 50 m of the seabed, closure to trawling and closure to all fishing methods. Given the logistics of monitoring partial closures and gear restrictions, the Ministry of Fisheries favoured a closure of specific seamounts to all types of fishing (Strategy 1999). Establishment of marine reserves is certainly not a new concept (Polunin 1983) but has become the generally accepted method for conserving shallow water benthic communities (Gray 1997; Done and Reichet 1998), especially when changes in trawl gear have limited potential to reduce the impacts of fishing (Probert 1999; Kaiser and de Groot 2000).

The draft New Zealand strategy is designed to evolve as new data become available. In this respect the Ministry of Fisheries allocated just over NZ$14 million over five years from June 2000 for research and management of marine biodiversity. Projects include database development, analysis and research on threats to biodiversity, and research on three key communities: seamounts, coastal waters in north-east New Zealand, and Antarctic waters in the Ross Sea. An additional NZ$16.9 million has been allocated to marine resource management initiatives, including the establishment of new marine reserves, the development of an integrated oceans management strategy, an education package on marine biodiversity and regional coordination of biodiversity management. A further NZ$3.5 million, from the Foundation for Research Science and Technology, has been allocated for defining seamount biological and physical characteristics and the effects of fishing on seamounts, and for the taxonomy of marine invertebrates and fishes.

Closure of Seamounts to Trawling

Nineteen seamounts around New Zealand were closed to bottom trawling in September 2000. All 19 seamounts are with in the EEZ, but outside the 12 n mile coastal zone, in depths from 220-1750 m (Figure 1). The shallowest seamount, Rumble III, is an active volcano north-east of the North Island; the deepest are two unnamed seamounts #140, north-west of Cape Reinga and seamount #328, south-east of the Chatham Islands (Clark *et al.* 2000). All of the closed seamounts have the potential to be fished, but most have had little or no fishing history. The closure of a few seamounts that have been fished, near to closed and unfished seamounts, will allow comparative research on the environmental impact of and recovery from trawling.

The closed seamounts were identified according to the criteria outlined above in section 7 (Strategy 1999), and are either representative of seamounts in their area or are unique features in the EEZ, eg Rumble III (Clark *et al.* 2000). The faunal compositions of many seamounts are not known, hence selection of seamounts was based more on geographical location and depth, than biodiversity.

The closed seamounts represent a small proportion of the known seamounts (19/800) and far less than the proportion of land protected in National Parks or coastal reserves within the territorial sea. Cynically the reserves may represent too little too late; key seamounts have been heavily exploited, and these productive seamounts, with high fish densities, could maintain the highest densities of invertebrates. Fishing is still permitted on most seamounts and the fishing industry is actively surveying unfished seamounts for potential new fish stocks. Nevertheless the closures represent a first step in protecting biodiversity on seamounts and comply with the precautionary principle of taking action with limited data (Roberts 1998, Fogarty 1999). The Ministry of Fisheries strategy allows for adjustments as new data become available on seamount biodiversity.

In the Australian EEZ a seamounts marine reserve was voluntary established in 1996, and formally declared in 1999. The reserve, on the slope edge south of Tasmania, covers 370 km^2 and is divided into two vertical management zones. An upper 500 m managed resource zone, to permit the tuna longline industry access to the upper waters, and a highly protected zone from 500m below the surface to 100 m below the seabed, to protect the benthic ecosystem from trawling and mineral exploration (Tasmania 1999). The reserve has an IUCN protected area management category 1a, and was established under the Australian National Parks and Wildlife Conservation Act 1975.

In other New Zealand fisheries, specific measures have been established for by-catch of mammals and seabirds, where it has been relatively easy to measure management results through observer coverage. The New Zealand sea lion *Phocarctos hookeri* breeds on the Auckland Islands and foraging animals are killed in a squid trawl fishery, which operates in the area over the summer period, when female sea lions are feeding pups. A 12 n mile exclusion zone has been established around the Islands and the industry operate a code of practice to minimise capture of sea lions. The catch of sea lions is monitored, by Ministry of Fisheries observers, and the squid fishery closed when the total number of sea lions captured in trawls exceeds the maximum allowable level of fishing related mortality set before each squid season (Doonan 1999). Seabirds are drowned in longline fisheries that target tuna *Thunnus* spp. and ling *Genytperus blacodes*. Various mitigation devices, such as tori lines, night setting and weighted hooks and lines, are employed to reduce the capture of birds when setting the gear (Murray *et al.* 1993). Research and management on sealions and seabirds are dependent upon data collected through the Ministry of Fisheries scientific observer programme on fishing vessels, but this programme will have limited value for monitoring biodiversity on seamounts.

Legislation and Guidelines for Management of Seamount Biodiversity

New Zealand legislation

The primary legislation for the management of seamounts is the Fisheries Act 1996. Fisheries resources have a broad definition in the Fisheries Act as any one or more stocks or species of fish, aquatic life, or seaweed; aquatic life is defined as any species of plant or animal life, at any stage of its life history that must inhabit water.

The Fisheries Act 1996 contains environmental principles derived from New Zealand's obligations under the United Nations Convention on Biological Diversity. The general principles are:

- Associated or dependent species should be maintained above a level that ensures their long-term viability.

- Biological diversity of the aquatic environment should be maintained.
- Habitat of particular significance for fisheries management should be protected.
- Adverse effects of fishing on the aquatic environment are to be avoided, remedied, or mitigated.

The Continental Shelf Act 1964 applies primarily to the exploration and exploitation of the natural resources of the continental shelf of New Zealand, and in particular minerals and petroleum. The continental shelf is the seabed and subsoil of the submarine area that extends beyond the territorial limits of New Zealand to the outer continental margin or to 200 n miles. The term natural resources includes living organisms belonging to sedentary species, and clearly overlaps with the Fisheries Act 1996, although the latter contains no reference to the Continental Shelf Act 1964. Management measures to close seamounts to trawling need also to be enacted under the Continental Shelf Act 1964 to prohibit or restrict mineral exploration on specific seamounts.

Additional legislation, such as the Marine Reserves Act 1971 and the Resource Management Act 1991, relate to the territorial sea, out to 12 n miles from the foreshore, and have limited contribution to seamount management. The Wildlife Act 1953 provides for the protection and control of wild animals and birds, and specifically includes a few marine species such as spotted black grouper, black corals, and red corals. The Territorial Sea, Contiguous Zone, and Exclusive Economic Zone Act 1977 established New Zealand's EEZ, but management of fish resources has been superceded by the Fisheries Act 1996.

International conventions and codes of practice

The New Zealand Fisheries Act 1996 is consistent with New Zealand's international obligations relating to fishing and protection of the environment. The relevant international codes and legislation relating to seamounts are summarised below and reflect a common theme in environmental protection:

United Nations Convention on the Law of the Sea 1982 (UNCLOS)

UNCLOS provides a framework for management of the marine environment and states are obliged to protect and preserve the marine environment. Article 194.5 specifically requires states to protect and preserve rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life.

Convention for the Protection of the Natural Resources and Environment of the South Pacific Region, 1986 (the Noumea Convention)

New Zealand is a party to the Noumea Convention, which was established in 1990 to promote the protection and management of the natural resources and environments among member states in the South Pacific. Member parties are expected to take appropriate measures to protect and preserve rare and fragile ecosystems and depleted, threatened or endangered flora and fauna as well as their habitat; and to establish protected areas, such as parks and reserves, and prohibit or regulate any activity likely to have adverse effects on the species, ecosystems or biological processes that such areas are designed to protect.

Convention on Biological Diversity 1992

The Convention on Biological Diversity was signed in 1992 and entered into force in 1993. It is a binding legal instrument and imposes obligations upon States that become parties to it. The Convention has three principle objectives: (1) the conservation of biological diversity, (2) the sustainable use of its components, and (3) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. New Zealand developed a biodiversity strategy, which highlighted seamounts as "jewels of the ocean", as a direct obligation under the Convention (Draft 1998). Article 8 of the Convention requires Contracting Parties to:

- Establish a system of protected areas or areas where special measures need to be taken to conserve biological diversity.
- Develop guidelines for the selection and management of protected areas or areas where special measures need to be taken to conserve biological diversity.
- Regulate or manage biological resources important for the conservation of biological diversity with a view to ensuring their conservation and sustainable use.
- Promote the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings.
- Endeavour to provide the conditions needed for compatibility between present uses and the conservation of biological diversity and the sustainable use of its components.

Food and Agriculture Organisation of the United Nations (FAO), Code of Conduct for Responsible Fisheries, 1995

The Code of Conduct for Responsible Fisheries provides general principles and standards for the management, development and conservation of fisheries. Article 7.2.2 of the Code states that appropriate management measures should provide, inter alia, that:

- Biodiversity of aquatic habitats and ecosystems are conserved and endangered species are protected.
- Adverse environmental impacts on the resources from human activities are assessed and, where appropriate, corrected.
- Catch of non-target species, both fish and non-fish species, and impacts on associated or dependent species are minimised, through measures including, to the extent practicable, the development and use of selective, environmentally safe and cost effective fishing gear and techniques.

Summary of Results and Lessons Learned

1) Deepwater fisheries developed in the New Zealand EEZ during the 1980s, targeting orange roughy and oreos. Currently around 70% of the orange roughy and oreo catch is taken by trawling on seamounts (Clark 1999).

2) An ITQ system, introduced in 1986, has generally been successful for single fish species management (Annala 1996). However orange roughy fisheries have been characterised by serial depletion of seamounts in east coast fisheries and the closure of the largest west coast fishery (Clark 1999). Most stocks are below 20% virgin biomass.

3) Seamounts appear to have a distinctive macro-invertebrate fauna to that found on the slope and soft sediment environments, although the fauna are poorly known with most samples derived from commercial trawls. Some macro-invertebrates are endemic to seamounts, long-lived (Clark *et al.* 1999; de Forges *et al.* 2000), and provide habitat for a large number of facultative species. Trawling has a negative impact on the dominant macro-invertebrate fauna on seamounts, crushing and removing corals (Probert *et al.* 1997; Koslow and Gowlett-Holmes 1998).

4) New Zealand is in the early stages of managing marine biodiversity. The Ministry of Fisheries developed a strategy to manage the impacts of fishing on seamounts. The strategy is incremental and recognises that there are limited data on seamount biodiversity and will accommodate new information (Strategy 1999).

5) Output controls, such as ITQs, are critical to the successful management of New Zealand's commercial species, but additional input controls are necessary for managing biodiversity of benthic invertebrates. Closed areas are globally recognised management tools for protecting biodiversity (Roberts 1998; Fogarty 1999; Probert 1999).

6) Nineteen (out of 800) seamounts were closed to commercial fishing in 2000. The closed seamounts were selected as a representative sample of seamounts throughout the EEZ, based on distribution, physical characteristics, and limited faunal data. The measures comply with New Zealand's obligations under International Conventions and codes of practice for management of marine ecosystems and biodiversity. Most closed seamounts have not been fished, but the inclusion of fished and unfished seamounts in one region will permit studies on the impact of and recovery from trawling.

7) "More research is needed" - the favourite cry of biologists. Taxonomic expertise is limited (eg Probert *et al.*1997), and the few experienced taxonomists have been overworked. Cataloguing and providing scientific descriptions of marine invertebrates may take years, but there is a need to move beyond species inventories to understand the genetic and ecological dynamics within and between seamount complexes.

8) There is a need to raise awareness of seamount biodiversity issues amongst policy makers in Environmental Departments and Ministries, and among non-government organizations and sectors of the seafood industry.

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Figures and Tables

Figure 1. Orange roughy *Hoplostethus atlanticus* fishery areas (light shading) in the New Zealand EEZ (dotted line), and seamounts closed to trawling (solid circles).

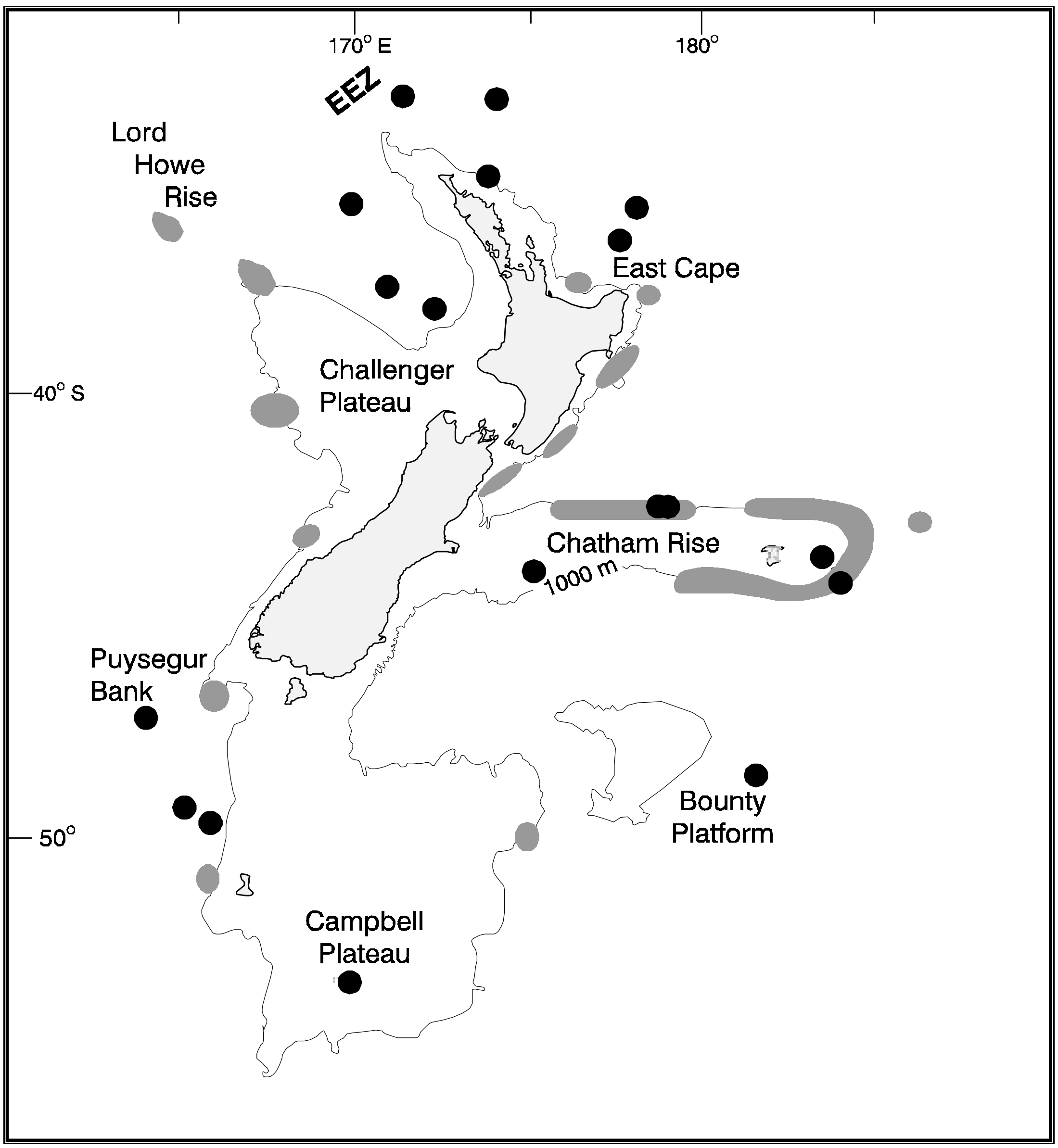

Figure 2. Orange roughy *Hoplostethus atlanticus* (left) and oreo *Allocytus niger* and *Pseudocyttus maculatus* (right) fishstock management areas within the New Zealand EEZ (dotted line).

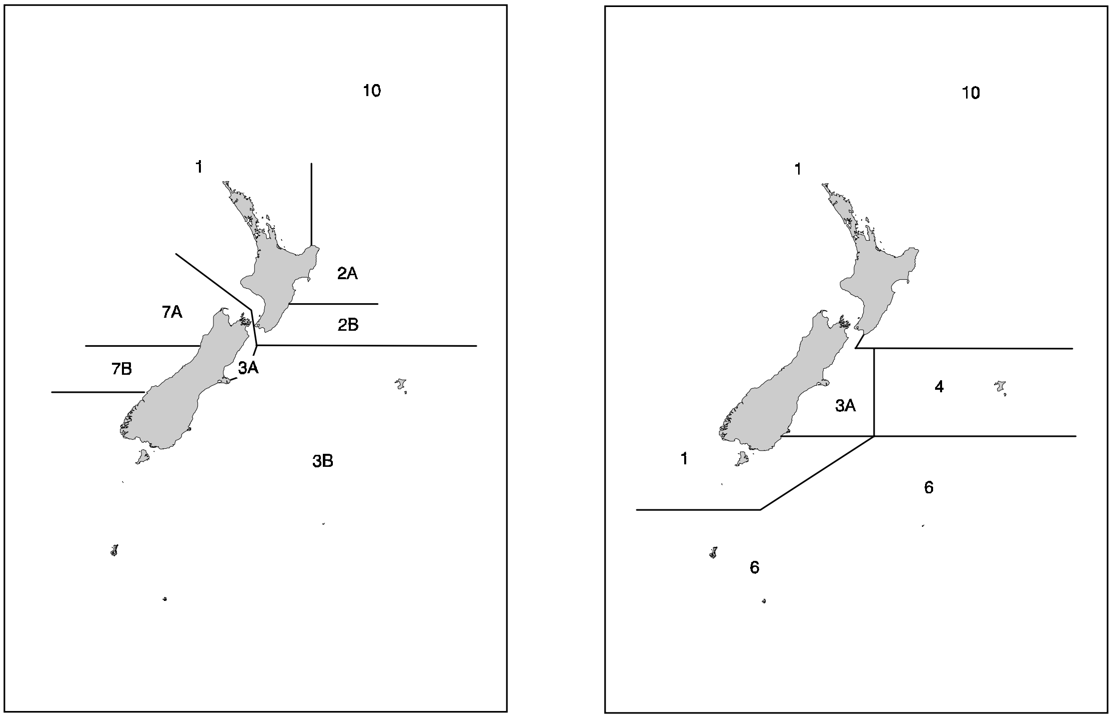

Table 1. Annual reported landings and TACs of orange roughy fishstocks in the New Zealand EEZ from 1981/82 to 1998/99 for the two main fisheries and totals for the EEZ.[2]

Fishing Year	ORH 7A		ORH 3B		Totals	
	Catch (t)	TAC (t)	Catch (t)	TAC (t)	Catch (t)	TAC (t)
1981/82*	4 248	-	28 200	23 000	35 902	-
1982/83*	11 839	-	32 605	23 000	43 802	23 000
1983/84	9 527	4 950	32 535	30 000	49 560	34 950
1984/85	5 117	4 950	29 340	30 000	43 179	36 450
1985/86	7 753	6 190	30 075	29 865	47 603	45 941
1986/87	11 492	10 000	30 689	38 065	48 326	58 920
1987/88	12 181	12 000	24 214	38 065	45 327	61 220
1988/89	10 241	12 000	32 785	38 300	50 898	62 474
1989/90	4 309	2 500	31 669	32 787	47 748	42 601
1990/91	1 357	1 900	21 521	23 787	34 731	37 947
1991/92	1 911	1 900	23 269	23 787	36 953	38 127
1992/93	2 087	1 900	20 048	21 300	32 448	35 441
1993/94	1 732	1 900	16 960	21 300	29 583	35 441
1994/95	1 636	1 900	11 891	14 000	22 449	27 468
1995/96	1 669	1 900	12 501	12 700	20 706	21 320
1996/97	1 308	1 900	9 278	12 700	16 645	21 328
1997/98	1 502	1 900	9 638	12 700	16 664	21 320
1998/99	1 249	1 425	9 372	12 700	16 058	20 345

[2] * Catches prior to 1983/84 are for an April-March fishing year; catches from 1984/85 onwards are for an October-September fishing year. From Annala *et al.* 2000.

Table 2. Total reported landings and TACs for combined oreo species fishstocks from 1982/83 to 1999/00.[3]

Fishing	Combined Oreo Fishstock									
Year	OEO 1		OEO 3A		OEO 4		OEO 6		Totals	
	Catch (t)	TAC (t)	Catch (t)	TAC (t)	Catch (t)	TAC (t)	Catch (t)	TAC (t)	Catch (t)	TAC (t)
1982/83	162	-	8 576	10 000	3 927	6 750	765	-	13 680	17 000
1983/83*	39	-	4 409	*	3 209	*	354	-	8 015	*
1983/84	3 241	-	9 190	10 000	6 104	6 750	3 568	-	22 111	17 000
1984/85	1 480	-	8 284	10 000	6 390	6 750	2 044	-	18 204	17 000
1985/86	5 390	-	5 331	10 000	5 883	6 750	126	-	16 820	17 000
1986/87	532	4 000	7 222	10 000	6 830	6 750	0	3 000	15 093	24 000
1987/88	1 193	4 000	9 049	10 000	8 674	7 000	197	3 000	19 159	24 000
1988/89	432	4 233	10 191	10 000	8 447	7 000	7	3 000	19 077	24 233
1989/90	2 069	5 033	9 286	10 106	7 348	7 000	0	3 000	18 703	25 139
1990/91	4 563	5 033	9 827	10 106	6 936	7 000	288	3 000	21 614	25 139
1991/92	4 156	5 033	10 072	10 106	7 457	7 000	33	3 000	21 718	25 139
1992/93	5 739	6 044	9 290	10 106	7 976	7 000	815	3 000	23 820	26 160
1993/94	4 910	6 044	9 106	10 106	8 319	7 000	983	3 000	23 318	26 160
1994/95	1 483	6 044	6 600	10 106	7 680	7 000	2 528	3 000	18 291	26 160
1995/96	4 783	6 044	7 786	10 106	6 806	7 000	4 435	3 000	23 810	26 160
1996/97	5 181	6 044	6 991	6 600	6 962	7 000	5 645	6 000	24 779	25 644
1997/98	2 681	6 044	6 336	6 600	7 010	7 000	5 222	6 000	21 249	25 644
1998/99	4 102	5 033	5 763	6 600	6 931	7 000	5 287	6 000	22 083	24 633
1999/00	3 709	5 033	5 859	5 900	7 034	7 000	5 914	6 000	22 516	23 933

[3] * Interim TACs applied. Catches prior to 1983/84 are for an April-March fishing year; catches from 1984/85 onwards are for an October-September fishing year. Data from Annala *et al.* 2000.