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A review of current knowledge describing New Zealand's deepwater benthic biodiversity

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EXECUTIVE SUMMARY

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This paper reviews information on New Zealand's deepwater benthic biodiversity, and makes recommendations on potentially at risk communities that could be the subject of directed research under the Biodiversity Strategy. Information was gathered through a series of interviews with relevant scientists in New Zealand and through literature and Internet searching.

Deepwater ecology and taxonomy are specialised fields, and there are a limited number of New Zealand scientists involved in them. Keith Probert and Dennis Gordon are two of the most prolific publishers, specialising in polychaetes and bryozoans respectively. Only a handful of directed studies on deepwater benthic communities came to light in this review. Published studies are the most instructive, but collections and databases at the National Institute of Water and Atmospheric Research (NIWA) and Te Papa Tongarewa Museum of New Zealand hold significant amounts of information, although in a less accessible format than published studies. The Chatham Rise stands out as the only area of New Zealand's EEZ where deepwater benthic biodiversity has been well studied.

Climate change, pollution, dumping, and mining are identified in the international literature as having potential impacts on deepwater benthic communities. However, bottom trawling is identified as the most pervasive human activity to potentially affect benthic communities in New Zealand. A plot of bottom trawling activity in New Zealand waters deeper than 1000 m shows the Kaikoura Canyon and the northern Macquarie Ridge to have significant fishing activity. These areas are also noticeably lacking in scientific information on their benthic communities, and are identified as potential areas for directed research under the Biodiversity Strategy.

INTRODUCTION

Biologists of the nineteenth century thought that the cold, dark, high-pressure environment of the deepsea was a barren wasteland devoid of life (Grassle 1989). Disproving this myth took practically a whole century from the publication of Jules Verne's vision in Twenty Thousand Leagues Under the Sea (Collie & Russo 2000). The Challenger expedition (1872–76) was the beginning of deepsea exploration, but it was not until the technological advances of the late twentieth century, when sampling methods were efficient enough, that accurate assessments of benthic diversity could be made in the deepsea (Nelson & Gordon 1997).

Technological developments, such as quantitative core sampling and trawls with closing doors, have made it possible to collect more species in a single sample than were collected in the entire Challenger expedition (Grassle 1978). Notwithstanding these advances, scientific exploration of the deepsea (83% of the oceans are deeper than 1000 m) is extremely patchy. The high cost of sampling in the deepsea has led to a bias toward research in the near-shore environments of developed countries. Further to the sampling costs, sample processing is expensive, time consuming, and not always possible, as there are few taxonomists worldwide who specialise in deepsea benthic fauna (Snelgrove 1998).

The limited studies of the deepsea benthos undertaken over the last 30 years have shown that not only can benthic species diversity be more readily compared to that of a rainforest than a desert, but the concept of a featureless, homogeneous environment is also incorrect. The deepsea may be less spatially and temporarily variable than shallow-water environments, but organic matter settling out of the water column (see Nodder 1998) encourages localised patches of high species diversity. Plankton blooms, seaweed, wood, kelp, and vertebrate carcasses are all sources of organic input to which benthic communities will respond (Grassle 1989).

On a larger scale, seamounts, hydrothermal vents, cold seeps, and trenches are features that can affect species diversity. Hydrothermal vents were discovered only in the late 1970s and the associated chemotrophic communities have been the focus of much attention (Probert 1999). More than 50 new genera from 20 new families have been discovered in hydrothermal vent communities (Grassle 1989). The biological communities in ocean trenches also show a high degree of endemism (50–90% of the fauna from each trench (Probert 1999)). However, the increased disturbance associated with upwelling, currents, and sediment slumping render trenches generally less biologically diverse than the low disturbance environment of the abyssal plains (Grassle 1989). Seamounts are not considered as part of this review although they are recognised as areas that support highly diverse and unique communities. Seamounts appear to be distinct from other deepsea communities in their abundance of large sessile epifauna (sponges, gorgonians, black corals, sceleractinian corals), and also show high levels of endemicity (Probert 1999).

Over the last 30 years there have been many discoveries of unique and often bizarre, highly diverse deepsea communities (Committee on Biological Diversity in Marine Systems 1995). Work by Grassle & Maciolek (1992) highlighted how little was previously known of deepsea sedimentary communities. Of the 798 species (from 178 families and 14 phyla) found in a sampling area of 21 m^2, 58% were new to science. Sixty-nine percent of the pericarid crustaceans were new to science, and in several polychaete families 75–93% of the species found were previously undescribed. Of particular importance to biodiversity research was their finding of a high degree of rarity in the samples: 90% of all species were represented by less than 1% of the individuals, and the most abundant species constituted less than 10% of the fauna. In addition to new and rare species, this study supported evidence from similar studies that species composition changed more rapidly across depth contours than along them.

Studies such as those noted above have led to estimates of total species abundance on the ocean floor (Grassle & Maciolek 1992, p. 336).

"Even very conservative extrapolations of these data to the enormous surface area of the deep ocean suggest that the number of species inhabiting the seafloor has been greatly underestimated (160,000 species, by Thorson, 1971). As more of the deepsea is sampled, the number of species will certainly be greater than 1 million, and may exceed 10 million."

Estimates of total species diversity derived by extrapolation have sparked extensive debate in the scientific community on the validity of such extrapolations and the estimates themselves.

"May (1992) used the ratio of undescribed to known species in Grassle and Maciolek's (1992) study to estimate that there are fewer than *500,000 species in the deepsea sediments.* Conversely, Poore and Wilson (1993) suggested that Grassle and Maciolek's (1992) study area was lower in diversity than some areas of the Pacific, and therefore may lead to underestimates of total species numbers. And Lambshead (1993) suggested that the diversity of meiofauna may exceed that of macrofauna, so that if Grassle and Maciolek's estimate is correct, there may be on the order of 100 million nematode species alone in the deepsea. Regardless of which estimate is correct, it is clear that there are many species in marine sediments, most of which are undescribed." (Snelgrove 1999, p. 130)

Research on the number and diversity of deepsea benthic species is important not only from a cataloguing perspective but also for our understanding of deepsea ecosystem dynamics. Macrofaunal organisms play a number of important roles in marine ecosystems, including secondary production and bioturbation of sediments. By feeding on organic matter sinking to the seafloor, macrofauna provide a conduit for transferring energy back into the water column when they are fed upon by bentho-pelagic species (Nodder 1998). Bioturbation of organic material and oxygen are very important factors controlling microbial activity in the sediments, and these processes make substantial contributions to oceanic nutrient cycling. Hence macrofauna have global-scale impacts on nitrogen, carbon, and sulphur cycling (Snelgrove 1998).

The Marine Biodiversity Programme within the Biodiversity Strategy aims to further our understanding of New Zealand's marine biodiversity by improving the management of marine biodiversity information, increasing our knowledge of selected marine communities, and identifying and assessing potential threats to biodiversity. The goal is to develop a more complete inventory of the biodiversity present in New Zealand's waters and to facilitate better state of the environment reporting. There have been a number of studies or exploratory programmes pertaining to deepwater benthic communities in New Zealand waters. Before embarking on the new phase of research that is possible under the Biodiversity Strategy, it is timely to review what has been investigated thus far, and what has been discovered. This review is intended to help direct future research in order to fill gaps in our knowledge, avoid duplication, and complement past research to ensure continuity where appropriate.

Definition of what constitutes "deep" varies between authors and studies. Snelgrove (1999) described deepsea habitats as those beyond continental shelves, or about 130 m in depth. Koslow et al. (2000) defined deepwater species as those living deeper than 500 m; J. D. M. Gordon (2001) considered deepwater fishing grounds as 500–1500 m; D. Gordon (1987) referred to deepsea bryozoan samples from deeper than 700 m. The cut off at 1000 m for this review is arbitrary.

METHODS

An atlas on fish and squid distributions (Hurst et al. 2000) was the starting point for this review. Interviews were then conducted with Dennis Gordon, Scott Nodder, and Steve O'Shea from the National Institute of Water and Atmospheric Research (NIWA), and Clive Roberts from The Museum of New Zealand Te Papa Tongarewa. These interviews led to further communication with other scientists including Keith Probert (University of Otago), and Martin Cryer, Simon Thrush, and Ashley Rowden (NIWA). All provided suggestions, information, papers, and manuscripts for use in this review. The Internet was also searched for relevant websites, particularly those providing general and international information.

Many of the studies sourced for this review considered a wide range of depths, with only some samples being taken from deeper than 1000 m. Early research technology did not allow sampling to this depth, therefore it is mostly modern studies that are detailed here. There are many studies not included in this review that touch on deepwater species and samples in New Zealand: however, the main focus of this review has been to source studies that have a sizeable deepwater (1000 m) content. For example, a number of reports by D. G. McKnight (1969a, 1969b, 1974) contain details of New Zealand research trawls that specifically investigated benthic communities, but very few of the samples were taken in water deeper than 300 m. There has also been a great deal of interest and investigation of seamounts in recent years. Seamounts have been specifically excluded from this review as work has already been compiled for the Ministry of Fisheries on this aspect of the deepsea environment (Clark et al. 2000).

The remainder of this document is structured in the following way. Significant sources of information regarding deepwater benthic biodiversity are broadly outlined in the results section and summarised in Table 1. Potential impacts on deepwater fauna are addressed and placed in a New Zealand context. Recommendations of communities for study are made based on the information sourced in this review and the potential impacts relating to those areas. Appendix 1 is an annotated bibliography of significant sources of information covered by this review.

RESULTS

Deepwater benthic ecology is a specialised scientific discipline, and there are few scientists working and publishing on this topic in New Zealand. Of those referenced in this review, Dr Keith Probert (currently at the University of Otago) is the most prolific publisher. He has published a number of studies on macrobenthic diversity and biomass, usually coauthoring with Don McKnight (NIWA) and/or Simon Grove (University of Otago). Dennis Gordon (NIWA) is actively publishing his work on bryozoans. There are many other authors and studies not mentioned here that touch on deepwater species and samples, but as mentioned above, the main focus of this review has been to source studies that have a sizeable deepwater content.

Aside from the lack of specialist scientists, study on deepwater benthic communities has been (and to some extent continues to be) limited by available technology and the high costs associated with deepwater exploration. These elements combined have resulted in only a handful of directed studies on the deepwater benthic communities of New Zealand's EEZ. Scientists in the field acknowledge the consequent information gap with comments such as "...given the dearth of detailed studies of benthic assemblages of New Zealand's shelf and slope..." (Probert & Grove 1998) and "In deeper New Zealand waters our taxonomic ignorance of meiofaunal organisms, which are highly significant in energy transfer and habitat modification, is total" (Nelson & Gordon 1997). The studies identified in this review are summarised in Table 1 and detailed in Appendix 1. The sources of information regarding deepwater benthic biodiversity fall into four basic categories, which are outlined below.

Published studies. Of all the sources of information about the deepwater benthos of New Zealand, work published in the scientific literature is the most instructive. Although many samples have been taken from deepwater, and held mainly in the NIWA collection (detailed in Appendix 1), they have not been reported on and referenced in as rigorous a manner as is required for publication. However, a number of published studies are derived from work undertaken using samples now housed in the NIWA collection. A greater emphasis is placed on describing benthic community composition in published papers over technical reports.

It is clear from Table 1 that, of the limited amount of directed research on deepwater benthic communities in New Zealand waters, the macrobenthos on the Chatham Rise has been a focus. This result can be attributed to the personal interests and specialised knowledge of Dr Probert, as well as the interest aroused by the topography and complex currents (Subtropical Convergence) of the Chatham Rise. Obviously this is a very small part of the entire deepwater component of New Zealand's EEZ, leaving most of it either unexplored or with opportunistic and/or unreported investigation.

Collections and databases. There are two major biological collections in New Zealand housing deepwater benthic specimens that have been accumulated from directed research, opportunistic sampling, and donations by scientists, fishers, and scientific observers. The marine biology collection at NIWA comprises mainly marine invertebrates, and this complements the collection of marine fishes, mammals, seabirds, molluscs, invertebrates, and algae at Te Papa (Nelson & Gordon 1997). Information regarding the specimens in these collections is held in databases as detailed in Appendix 1. Although these collections make a significant contribution to our knowledge of deepwater benthic species in New Zealand, much of the information is not readily accessible. Exceptions include the *NIWA Biodiversity Memoir* series – mainly taxonomic monographs resulting from NIWA's Marine Biodiversity and Systematics Programme (these do not deal exclusively with deepwater groupings). There is also the occasional review of taxa or families housed in the collections, such as that of deepsea Bryozoa by Gordon (1987) (see Table 1 and Appendix 1).

Scientific reports. Since oceanic and fisheries research began in New Zealand there have been a number of scientific series reporting the details of these studies. These reports are in addition to the contributions of DSIR and NIWA staff to formal scientific publications (2000 published papers from 1952 to 1996: see Thompson 1987, 1996), and it does not necessarily follow that all internal reports become published works. Subsets of all the internal reports are concerned with deepwater fisheries research trawls conducted for the Ministry of Fisheries. In technical reports, benthic species tend to be a side issue rather than a focus.

Research trawling has covered more than 5300 km^2 of the seafloor within the EEZ (0.13% of the estimated 4 053 049 km^2), although most trawls were less than 1200 m depth. Between 1961 and 1997, 13 566 tows were carried out. These have added significantly to our knowledge of fish diversity, distribution, and abundance, but regrettably little bycatch was recorded or added to scientific collections until recently. However, the mesh size used in most trawl surveys (4 cm diameter) will have excluded most components of benthic diversity (Nelson & Gordon 1997). A number of these reports are included in the annotated bibliography (Appendix 1) as they are sources of information relevant to this review, even though the reports themselves do not make a significant contribution to our knowledge of deepwater benthic biodiversity. New or unusual bycatch specimens caught in research trawls are sent to the collections at NIWA or Te Papa as detailed in Appendix 1. It is by this opportunistic sample collection that research trawls provide information about New Zealand's deepwater benthic biodiversity.

Scientific Observer Programme. One of the primary tasks of the Ministry of Fisheries Scientific Observer Programme is to provide catch-effort data to the Ministry for the purposes of stock assessment work. Observers provide full descriptions of a catch, rather than the fishers' requirement to record the top five commercial species (although this varies depending on the fishery). The recording, collection, and preservation of unusual biological material for scientific examination and archiving are secondary tasks (N. Smith, Ministry of Fisheries, pers. comm.). Although each trip report contains a list of all the specimens collected by the observers, at present they are supplied only with a fish identification guide, making the identification of invertebrate bycatch difficult (G. Dickie, Ministry of Fisheries Observer Officer, pers. comm.). Although the observer programme collects a vast amount of information, there is no specific reporting mechanism for bycatch information. Rather, relevant information and samples are passed on to NIWA or Te Papa and become (an often valuable) part of these collections and databases.

Table 1: Summary of published studies and databases providing information on New Zealand's deepwater benthic biodiversity.

Author / source of information	Location	Method	Aim/ focus	Major findings/comments
Probert & McKnight (1993)	Chatham Rise	Anchor–box dredge at 23 stations, 244–1394 m water depth.	To examine the distribution of macrobenthic biomass across the Chatham Rise.	Faunal density and biomass correlated. Increased biomass on the south side of the Rise possibly related to enhanced primary productivity.
Probert et al. (1996)	Chatham Rise	Anchor–box dredge at 23 stations, 244–1394 m water depth.	Distributional ecology of polychaete assemblages (macrofauna), and their relationship to major environmental gradients.	At least 136 polychaete species from 37 families. Community composition with depth, and between northern and southern slopes of the Chatham Rise showed variations related to organic flux.
Probert et al. (1997)	Chatham Rise	Invertebrate bycatch from 73 orange roughy trawls examined.	Compare benthic invertebrate bycatch from "hills" and "flats" in ORH fishery.	96 species recorded from 82% of tows. Bycatch composition at hills and flats differed significantly.
McKnight & Probert (1997)	Chatham Rise	Sledge trawl at 40 stations, 237–2039 m water depth.	Characterise epibenthic communities across the Chatham Rise.	218 taxa collected, predominantly echinoderms, crustaceans, and molluscs. Three communities identified, characterised by depth and sediments.
Probert & Grove (1998)	South Island west–coast	Anchor box dredge at 30 stations, 32–1120 m water depth.	Identify major macrobenthic assemblages, composition, and distribution with respect to environmental gradients.	"Deep" assemblage (477–1120 m) on sandy-mud sediments. Mean biomass of macrofauna decreased markedly with depth.
Gordon (1987)	New Zealand	Reporting on NZOI specimen holdings.	Describe the deepsea (>700 m) bryozoa in the NZOI collection.	240 deepwater bryozoans recorded from 49 families and 117 genera. 80% considered to be NZ endemic.
Gordon (1999)	NZ and Australia	Review of published and unpublished records.	Summarise what is known of bryozoan diversity in NZ and Australia based on published and unpublished records.	932 bryozoa in the NIWA collection. Maximum species diversity at 200 m, declining sharply to 700 m. Few deepsea samples taken. Many endemics.
Grove & Probert (1998)	Bathyl areas of eastern and southern New Zealand	Megabenthic bycatch from hoki and orange roughy trawl surveys, April 1992–August 1995.	Analyse the distribution and abundance of megabenthic bycatch to assess potential impacts of demersal trawling on deepwater benthos.	Bycatch varied greatly between tows, between hoki and ORH trawls, and between areas. Asteroids, holothurians, sponges, anemones, and echinoids were most common and had highest biomass. Many management recommendations made.
NIWA marine biology collection and database (principally *invertebrates)*	NZ EEZ (+ Pacific Islands and the Ross Sea)	Systematic seafloor samples and opportunistic specimen collection.	The database catalogues all identified specimens in the NIWA collection, beginning 1956 to the present day. Location, depth, method, ancillary habitat data recorded.	Significant source of information regarding benthic biodiversity, species distributions, and biological assemblages. Accessibility of information is an issue.
Te Papa Tongarewa Museum of New Zealand – fish collection	NZ EEZ (+ Pacific Islands and the Ross Sea)	NZOI sampling campaign 1954–1980s. Ad hoc contributions ongoing.	Museum collection: to identify and preserve fish specimens. Taxonomic identification ongoing. Database entry ongoing (*Te Kahui*).	Scientific publications and monographs provide information about the collection. FRST–funded publication expected 2005.

Potential impacts on deepwater benthic communities

There has been limited research on New Zealand's deepwater benthic communities. It is not appropriate, therefore, to attempt to identify representative communities for specific research, as any directed research on deepwater benthic communities will make a significant contribution to our knowledge of biodiversity in this area. There is, however, the opportunity to identify potentially impacted communities by considering the threats facing New Zealand's deepwater benthos.

There are an increasing number of studies being conducted and global literature produced which investigate the effects of human activities on the deep seabed. According to the World Conservation Monitoring Centre, the effects of global warming have already been measured in the deepsea with an increase in abyssal temperature of 0.32 °C in 35 years being attributed to climate change associated with human activities (http://www.unep.ch/seas/main/hchange.html 15/08/01). On a similarly large scale, pollution and run-off from land-based activities and atmospheric sources have been observed on the seafloor (Committee on Biological Diversity in Marine Systems 1995) and in deepwater fish species (Porte et al. 2000). More direct human impacts on deepsea benthic communities include trawling, dredging, dumping, and mining.

Morgan et al. (1999) reviewed environmental data on the impacts of deep seabed mining collected over the previous 25 years. Although investigation of the potential for deepsea exploration is ongoing, the impacts of these activities are not expected to cause serious environmental harm. In the New Zealand EEZ, the density and abundance of manganese nodules is not believed to be significant enough to consider mining as an economically viable option in the near future (S. Nodder, NIWA, pers. comm.).

Messieh et al. (1991) comprehensively reviewed trawling, dredging, drilling, and dumping activities, detailing the effects on the sediments, habitats, and communities. The toxicity and behaviour of waste products from petroleum drilling are generally well understood, and the size of impact zones predictable. Dredging can affect the stability of the seabed, and dumping of dredge spoil and industrial/metropolitan waste smothers benthic communities, with continued resuspension of fine materials. The review concluded that it is clear that extensive fishing activity can produce long-term changes in sediment characteristics and benthic community structure. Although bottom trawling in water deeper than 1000 m is now commonplace, oceanic dredging, drilling, and dumping in New Zealand is confined to shallower waters at present. The economic needs of the future may drive technological advancement, making these activities viable. It will then be appropriate to review overseas research regarding the effects of these activities on the benthos.

Jones (1992) reviewed the environmental impacts of trawling on the seabed.

"Fishers have been complaining about the effects of bottom trawling gear on the marine environment since at least the 14th century. Trawl gear affects the environment in both direct and indirect ways. Direct effects include scraping and ploughing of the substrate, sediment resuspension, destruction of the benthos, and dumping of processing waste. Indirect effects include post-fishing mortality and long-term trawl-induced changes to the benthos. There are few conclusive studies linking trawling to observed environmental changes since it is difficult to isolate the cause. However, permanent faunal changes brought about by trawling have been recorded. Research has established that the degree of environmental perturbation from bottom trawling activities is related to the weight of the gear on the seabed, the towing speed, the nature of the bottom sediments, and the strength of the tides and currents. The greater the frequency of gear impact on an area, the greater the likelihood of permanent change. In deeper water where the fauna is less adapted to changes in sediment regimes and disturbance from storm events, the effects of gear take longer to disappear. Studies indicate that in deepwater (>1000 m), the recovery time is probably measured in decades."
(Jones 1992, abstract, page 59)

Dayton et al. (1995) considered the environmental effects of marine fishing, including a section specifically dedicated to benthic communities in the deepsea (p. 213).

"Deepsea communities are characterized by life-history adaptations such as slow-growth, extreme longevity, delayed age of maturation, and low natural adult mortality. Also they are often characterized by fragile structures that have important community roles (Levin et al. 1991). Such adaptations are characteristic of systems with low productivity and turnover; they are extremely vulnerable to human intervention such as fishing (Messieh et al. 1991; Thiel and Schriever 1990); and there is considerable risk attendant to any disturbance in this habitat... Anecdotal stories of the New Zealand orange roughy taken in spawning aggregations over deepsea pinnacles at about 1000 m depth report that when the fishery began the trawls bought up a great deal of benthic life; but almost all such incidental take has ceased (Jones, 1992)... Given the extent of the extremely heavy trawl fisheries, much of the world's shelf communities may have already been altered."

Validated catch effort data held in the Ministry of Fisheries (*Warehou*) database allows plots of fishing activity to be constructed. As bottom trawling is considered to be an activity that threatens benthic communities, a plot of bottom trawling activity in New Zealand is instructive as to areas of the seafloor that contain potentially impacted benthic communities (Figure 1). Bottom-trawling activity is concentrated close to the 1000 m contour, with very limited activity in water much deeper than this. Deepwater fishing activity is spread almost the length of New Zealand, specifically on the east coast from East Cape to the Catlins, with the greatest concentrations of effort between the Wairarapa and Kaikoura coasts. There are also patches of intense activity south of Fiordland at the northern end of the Macquarie Ridge, and on the northwest edge of the Challenger Plateau (outside the EEZ).

The locations of deepwater sampling stations for which there is benthic biodiversity information in the NIWA marine biology collection and database are shown in Figure 2. As already discussed, there has been a focus of directed research on the Chatham Rise, and this figure shows that there are also a number of sampling stations in the areas of fishing activity around the Rise. There is fairly good coverage of benthic samples from East Cape to the Catlins where there is heavy fishing pressure. However, although samples have been taken from all the stations shown in Figure 2, this does not translate into the availability of biodiversity information at these points.

Recommendations

Criteria for assessing research proposals are outlined in the Ministry of Fisheries medium term research plan for biodiversity. Priority should be given to research on communities that:

i are considered under pressure from human impacts
ii are considered unique or special
iii and/or have not previously been the subject of scientific investigation.

Given the quality and quantity of research available, it would be a very difficult task to identify benthic communities that are considered unique or special in the deepsea. Communities that can be considered under pressure from human activities are to some extent identified in Figure 1, since bottom trawling is the most persistent human activity likely to affect deep benthic communities in New Zealand waters. The greatest fishing pressure appears to be in the region of the Kaikoura Canyon, making it an ideal region in which to conduct research. Other factors make the area suitable for scientific study. 1) The proximity of the canyon to the South Island and major ports making sampling an easier undertaking than distant offshore sites. 2) The high productivity of the area as evidenced by the degree of fishing there, and by the presence of (and tourism industry based on) sperm whales. 3) There has been, and continues to be, a large amount of scientific research in the area based on the presence of these whales, with additional studies of chemical and physical oceanography to compliment these observations (University of Otago Marine Science and Environmental Science Departments). 4) The topography of the area lends itself to benthic sampling over a wide range of depths in a small sampling area. And 5) the sediments in the region are dominated by mud (particles under 0.063 mm) with areas of subsidiary medium and fine grain sand (0.063–0.5 mm) likely to support benthic infaunal communities (McDougall 1982).

A second area with potentially high trawling impacts is the Macquarie Ridge (in particular the northern end from 48 to 50° S). There have been very few benthic samples taken in the area according to the NIWA collection (Figure 2), and the literature search conducted for this review has turned up no other sources of information about the area. Like the Kaikoura area, there is the potential for sampling a wide range of depths in a small area. The northern Macquarie Ridge (over 500 m depth) is sandwiched by the Puysegur Trench and Solander Trough (up to 6000 m deep). There appears to be a complex sedimentary regime in the area, with the top of the Macquarie Ridge dominated by biogenic–calcareous gravel/sand, which is known to harbour rich and diverse communities elsewhere (S. Nodder, pers. comm.). Sediments in the Solander Trough are dominated by terrigenous-mud, with a subdominant biogenic-calcareous ooze fraction, and the Puysegur Trench is also biogenic-calcareous ooze, and deep ocean clays (Mitchell et al. 1989). The topographical and sedimentary complexity make this an interesting area to study regardless of the fact that the benthic community may be under significant pressure from fishing activity, and it has not been the subject of scientific investigation in the past.

Aside from recommending the Kaikoura Canyon and Maquarie Ridge areas for specific investigation, any additional studies funded by the Biodiversity Strategy are sure to improve our current knowledge of marine biodiversity. It is also clear that while there is a need for directed research on deepwater benthic communities, there are also opportunities to obtain useful biodiversity data using current information gathering exercises, such as fisheries research trawls and scientific observers (Grove & Probert 1998). Despite the inadequacies of the trawl net as a sampling device for benthic communities (Probert et al. 1997) there are few other sources of information about the deepsea, and maximum use should be made of the opportunities fishing provides to gain knowledge. A great deal of benefit could also be gained from thorough examination and publication of the samples held in the NIWA marine biology collection..

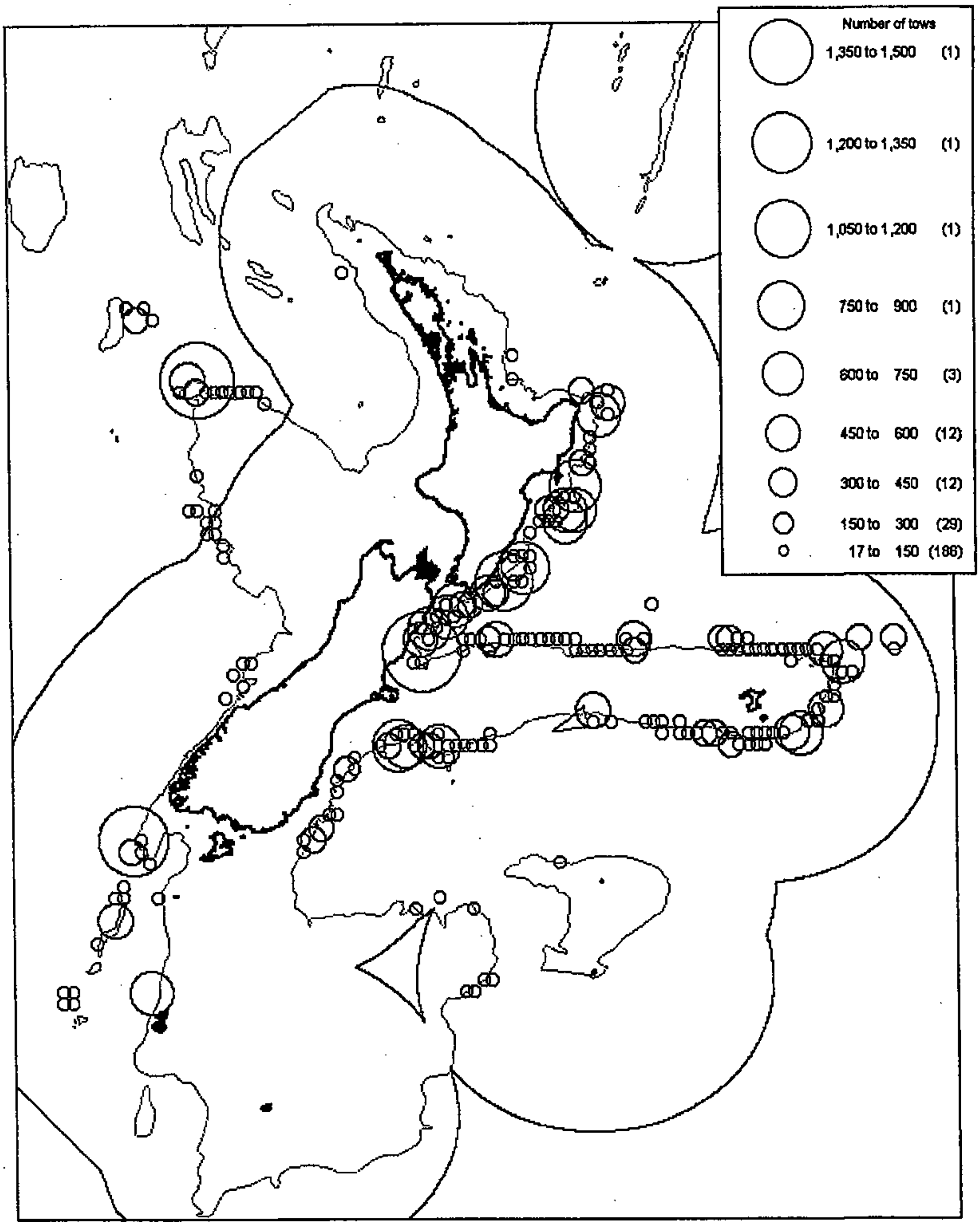

Figure 1: Bottom fishing activity (bottom trawl and bottom pair trawl) in water deeper than 1000 m, October 1989 – June 2001. Plot includes New Zealand's EEZ boundary (red) and 1000 m depth contour (orange). Courtesy of Ministry of Fisheries Information Management Group.

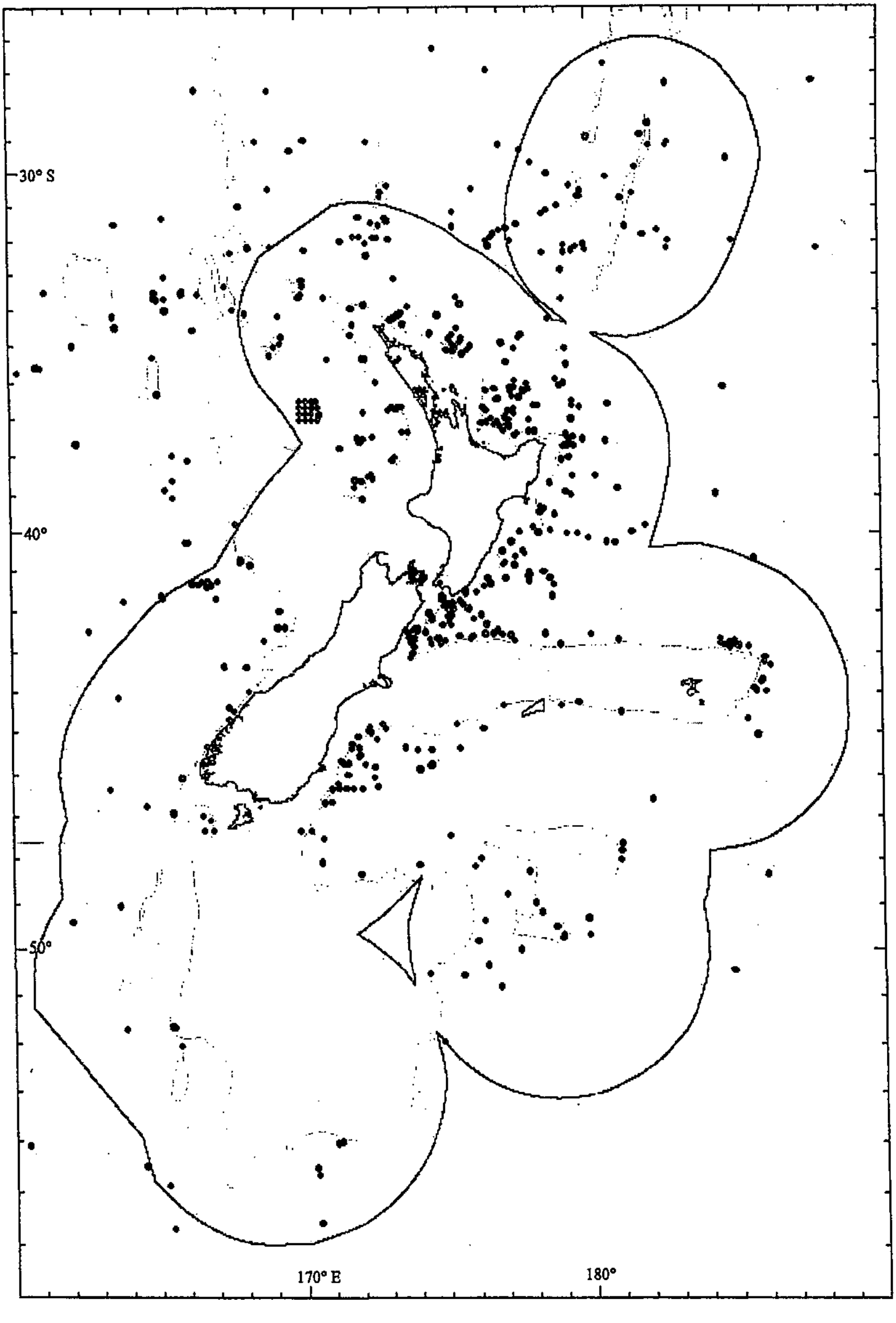

Figure 2: NIWA biology stations deeper than 1000 m: January 1955–August 1994. Plot includes New Zealand's EEZ boundary (red) and 1000 m depth contour (orange). (Courtesy of A. Rowden and R. Singleton, NIWA)

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Appendix 1. Annotated bibliography

Published Papers

Gordon, D.P. (1987). The deepsea bryozoa of the New Zealand region. pp. 97–104, *In* Ross, J.R.P. (ed.) Bryozoa: present and past. Proceedings of the 7th International Bryozoology Association conference. Western Washington University, Bellingham, Washington, 1986.

Dennis Gordon undertook a study of the bryozoans in the New Zealand Oceanographic Institute collection (now incorporated into the NIWA collection) as it was recognised that very few New Zealand bryozoans had been described. One hundred and twenty two out of 1447 NZOI stations deeper than 700 m yielded bryozoans. A total of 240 species of deepwater bryozoans are recorded from 49 families and 117 genera. Over 80% of these species were considered endemic to New Zealand at the time of publication.

In line with international studies, the number of bryozoan species at each station decreased with depth, markedly so between 1000 and 2000 m. For the 1000–1500 m depth interval, the New Zealand region recorded a remarkable 45% of the total species worldwide. Rooted species predominate on soft sediments, with encrusting forms on hard bottoms.

This publication stands alone as a source of information regarding an important component of New Zealand's deepwater benthic biodiversity.

Gordon, D.P. (1999). Bryozoan diversity in New Zealand and Australia. pp. 199–204, *In* Ponder W.; Lunney, D. (eds), The Other 99%: the conservation and biodiversity of invertebrates. Transactions of the Royal Zoological Society of New South Wales, Mosman.

Estimates of New Zealand bryozoan diversity, based on published literature and ongoing study of the NIWA biology collection, stand at 932 species (marine and freshwater). Maximum marine species diversity occurs in the shallowest 200 m, thereafter declining sharply and evenly to 600–700 m, below which the rate of decline lessens considerably. Fewer than 4% of NIWA's samples were taken deeper than 2000 m, so the number of previously undescribed species in the deepsea may be expected to increase.

This is a useful review of knowledge of bryozoan diversity in New Zealand.

McKnight, D.G.; Probert, P.K. (1997). Epibenthic communities on the Chatham Rise, New Zealand. *New Zealand Journal of Marine and Freshwater Research 31:* 505–513.

McKnight & Probert (1997) studied epibenthic macrofauna on the Chatham Rise using a small sledge at 40 stations along three transects, from 237 to 2039 m water depth: 218 taxa were collected, predominantly echinoderms, crustaceans, and molluscs. Three epibenthic communities were identified by multivariate analysis:
A: 237–602 m on predominantly sandy sediments from the crest and shallow flanks of the Rise.
B: 462–1693 m on muddy sediments characterised by *Ypsilothuria bitentaculata*, *Pentadactyla longidentis* (Holothuroidea), *Brissopsis oldhami* (Echinoidea), and *Amphiophiura ornata* (Ophiuroidea), mainly on the northern slopes of the Rise.
C: 799–2093 m on muddy sediments including characteristic species *Ophiomusium lymani* (Ophiuroidea), *Porcellanaster ceruleus* (Asteroidea), *Gracilechinus multidentalus* (Echinoidea), and *Aeneator recens* (Gastropoda), predominantly at the southern stations on the central transect.

The depth distribution of communities B and C varies on the north and south sides of the Chatham Rise. Of the 218 taxa, a considerable number were undescribed, some were widely distributed at bathyl depths, and *Ophiomusium lymani* and *Hyolinoecia tubicola* are both global continental margin species. Although not thoroughly analysed in this study, there were indications that the identified communities differed with regard to trophic status. Mobile crustaceans likely to be scavengers or carnivores were prominent among community A, whereas the two deeper communities lacked highly mobile predators but included more deposit feeders.

Probert, P.K.; McKnight, D.G. (1993). Biomass of bathyl macrobenthos in the region of the Subtropical Convergence, Chatham Rise, New Zealand. *Deepsea Research I, 40 (5):* 1003–1007.

Probert & McKnight estimated biomass of macrobenthic infauna from 23 anchor–box dredge samples positioned along three transects across the Chatham Rise, in water depths of 244–1394 m. The fauna was numerically dominated by polychaetes and pericarid crustaceans. Faunal density and biomass were significantly correlated ($p<0.001$). The data for all stations showed no correlation between biomass and water depth. Biomass on the south side of the Rise tended to be higher than on the north. Stations north of the crest of the Rise showed a significant inverse relationship between biomass and depth, but stations south of the crest showed no correlation. There is evidence of enhanced productivity associated with the Subtropical Convergence, and the authors expect differences in productivity across the front to have a noticeable effect on benthic biomass. Further results from this sampling were discussed by Probert et al. (1996) (below).

Probert, P.K.; Grove, S.L.; McKnight, D.G.; Read, G.B. (1996). Polychaete distribution on the Chatham Rise, Southwest Pacific. *Internationale Revue der Gesamte Hydrobiologie 81 (4):* 577–588.

Probert et al. (1996) investigated polychaete distribution on the Chatham Rise. Samples were obtained using an anchor-box dredge and sieved through a 1 mm mesh to retain macrofauna. Multivariate analysis was performed using the PRIMER suite of programs. Three north–south transects across the Chatham Rise consisted of 23 sampling stations in water ranging from 244 to 1394 m depth. Polychaetes were numerically dominant in all but one sample. Amphipods, isopods, and ophiuroids were the next most abundant groups. The polychaetes collected represented 37 families and at least 126 species. Cluster analysis identified two major groupings, with depth identified as the best correlator with the ordination pattern. The "deeper" group; 802–1394 m, had *Aricidea* (Allia) sp.A, *Leanira* sp., *Leitoscolopos* sp., *Poecilochaetus trachyolerma*, ?*Diplocirrus* sp.A, and *Terebellides* aff. *stroemi* as characteristic species. The polychaete fauna of the New Zealand bathyl zone is poorly known, and this precluded the authors from discussing these results in the wider context of polychaete assemblages and distributions on a national scale.

Probert, P.K.; McKnight, D.G.; Grove, S. L. (1997). Benthic invertebrate bycatch from a deepwater trawl fishery, Chatham Rise, New Zealand. *Aquatic Conservation: Marine and Freshwater Ecosystems 7:* 27–40.

Probert et al. (1997) investigated the benthic invertebrate bycatch from orange roughy trawls at 662–1524 m on the Chatham Rise. Of the 73 trawls examined, 82% had benthic bycatch and cluster analysis showed the bycatch to differ significantly between 'flats' and 'hills' (seamounts). Groups that were conspicuously more common in the flat tows (754–1524 m) were Pennatulacea, Natantia, Polychelidae, Asteroidea, Echninoidea, and in particular Holothuroidea (taken in 53% of flat tows and no hill tows).

From visual observations it was evident that bycatch volume was largest from hill stations and was dominated by cnidarians. No scleractinians, stylasterids, or antipatharians were collected from flat tows, but these were important taxa on hill features. Exposed rock surfaces are relatively uncommon in the deepsea, but their occurrence on seamounts provides a major opportunity for the development of communities dominated by attached epifauna. By contributing an important structural dimension, such life forms provide opportunities for many associated species, thereby creating patches of enhanced biodiversity.

The authors point out that bycatch does not represent a complete picture of the benthic community. Bobbins set along the ground rope of the trawl net are likely to crush macrobenthic animals and the size of the net mesh will also exclude small animals. Some body forms were observed to be more susceptible to being taken by the trawl net, including large upright species (black coral), spiny species that snag easily (stylasterids and brisingids), and soft species that can become pinched in the net mesh (holothurians).

This paper also contains interesting and informative sections on vulnerable taxa, other impacts of trawling on the benthos, benthos–fisheries interactions, and a brief discussion of management tools and responsibilities that apply to seamounts and the deepsea. As such, it makes an important contribution to the literature on New Zealand's deepwater biodiversity and the management of threats facing our fauna. Concerns raised on the impacts of fishing on seamount faunas have been partially addressed by the closure of 19 seamounts to fishing in the New Zealand EEZ by the Minister of Fisheries, effective as of May 2001. Seamount research is proposed in the Ministry of Fisheries biodiversity medium term research plan, Fisheries Research Services document, and also funded by FRST (Seamounts: their importance to fisheries and marine ecosystems).

Probert, P. K.; Grove, S. L. (1998). Macrobenthic assemblages of the continental shelf and upper slope off the west coast of South Island, New Zealand. *Journal of the Royal Society of New Zealand 28 (2):* 259–280.

Probert & Grove (1998) studied macrobenthic assemblages off the South Island's west coast between Karamea and Cook Canyon. Samples were taken using an anchor-box dredge, sieved through 1 mm mesh, and processed using the computer software PRIMER. Four samples were from water deeper than 1000 m, and formed part of an assemblage of 'deep' stations from 477 to 1120 m. This assemblage was in sandy-mud and good species discriminators were *Apseudes diversus* (Tanadacea) and *Ophiozonella stellamaris* (Ophuridae).

The mean biomass (wet weight) of macrofauna decreased markedly with depth from 79.4 g m^{-2} in the shallowest group of samples (32–51 m), to 5.6 g m^{-2} in the deep group. Ordination of polychaete genera indicated similarities between shallow (less than 500 m) west coast samples and directly comparable samples from the east coast (Probert et al. 1996). However, deeper samples did not show great similarities with east coast studies, primarily because polychaetes were not valuable as diagnostic species in deeper samples.

The authors conclude by acknowledging that "the dearth of detailed studies of benthic assemblages of New Zealand's shelf and slope" impeded their ability to evaluate possible biogeographic processes contributing to this pattern.

Technical Reports

Hurst, R.J.; Bagley, N.W.; Anderson, O.F.; Francis, M.P.; Griggs, L.H.; Clark, M.R.; Taylor, P.R. (2000). Atlas of juvenile and adult fish and squid distributions from bottom and midwater trawls and tuna longlines in New Zealand waters. *NIWA Technical Report 84.* 162 p.

This report details the spatial distribution of a wide range of New Zealand fish and squid species (see also Anderson et al. (1998) and Bagley et al. (2000)). This information is gathered from research trawls 1961–1997, and scientific observer trawls 1980–1998. Species that have a significant proportion of trawls at depths greater than 1000 m include black oreo (*Allocyttus niger*), orange roughy (*Hoplostethus atlanticus*), and smooth oreo (*Pseudocyttus maculatus*). Consequently, these are the fisheries that could potentially have impacts on deepsea benthos (see objective 2). Figure 3 shows the type of information available in this review.

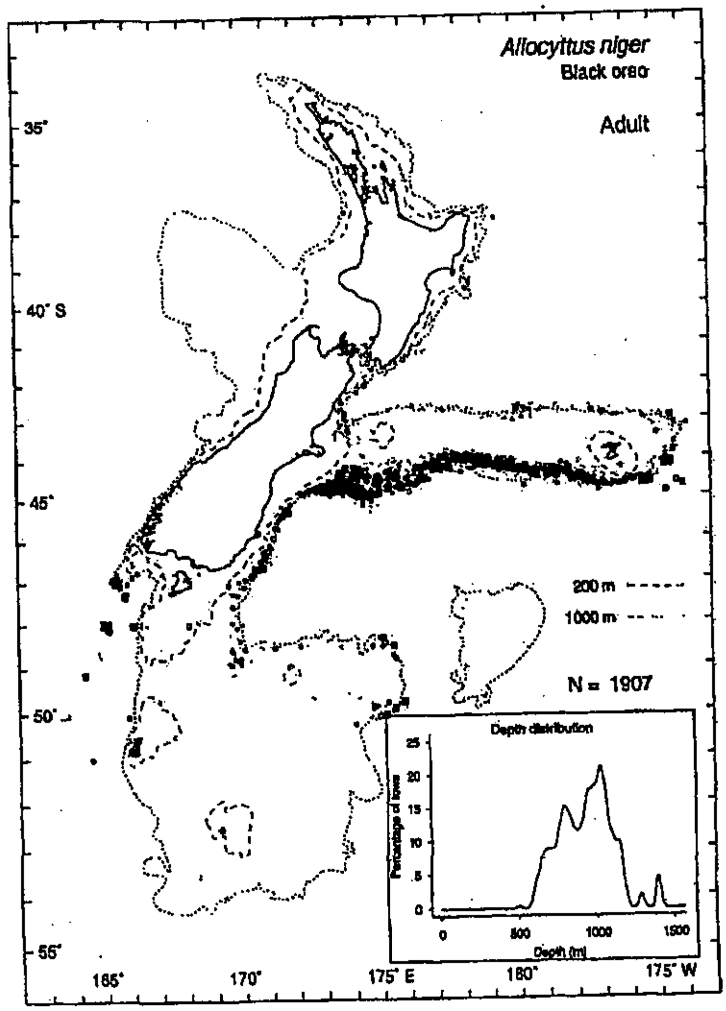

Figure 3: Geographical and depth distribution of bottom trawls containing adult black oreo (*Allocyttus niger*) (from Hurst et al. 2000).

Other Reports

McMillan (1985), Clarke & King (1989), Tracey et al. (1997), Anderson et al. (1998), Hart & McMillan (1998), Clark & Anderson (1999), and Bagley et al. (2000) reported biomass surveys, or exploratory trawls of new fishing areas. They all provide essentially the same information about the target species (length, weight, sex, gonad stage), or a number of commercial species, with little or no information about invertebrate bycatch. Typically, any bycatch information is not broken down by depth or area, and as the surveys tend to cover quite extensive areas and depths, the information provided cannot be used to learn anything of benthic biodiversity below 1000 m. Bottom trawling was certainly conducted in deepwater and benthic bycatch was possibly recorded or collected in some way, but these details are not presented in these reports.

Grove, S.L.; Probert, P.K. (1998). Bycatch of megabenthic invertebrates from bathyl trawl fisheries off southern and eastern New Zealand. *NIWA Technical Report 13.* 28 p.

Grove & Probert (1998) analysed megabenthic bycatch of 14 hoki and orange roughy trawl surveys between 1992 and 1995. Only the invertebrate macrofauna that entered the processing area was weighed and recorded, though this is likely to underestimate considerably the invertebrate bycatch actually retrievable from the net.

Invertebrate bycatch had a very high variability among the many hundreds of tows. There was variation between fishing areas, between hoki and orange roughy trawls, and significant differences in the bycatch of flat areas and topographic features (pinnacles and drop-offs). There is an interesting discussion of the interpretation and use of bycatch data in assessing benthic community structure and biodiversity.

"There are difficulties in using these data to assess the effects of trawling on the benthos and for investigating large-scale patterns of benthic structure. The data probably considerably underestimate benthic invertebrate bycatch: for 66% of tows, no bycatch was recorded. Most of the invertebrate bycatch does not appear to reach the processing area. From direct examination of the net and deck after 73 orange roughy trawls on the Chatham Rise, Probert et al. (1997) recorded benthic invertebrate bycatch from 60 tows (82%) after the catch had been discharged, whereas the records for the same tows, based on material reaching the processing area, show bycatch for 5 (7%).

To undertake the analysis, assumptions had to be made about the data that may be invalid. It had to be assumed that if no invertebrate bycatch was recorded for a tow, then none was observed. However, recording invertebrate bycatch would be of low priority compared to obtaining fish data, and under some circumstances might be ignored.

Apparent differences between areas may be real or due to inconsistencies in the recording of bycatch. For example, on TAN9204, 41 trawls were made and no bycatch was recorded, but after a crew change 42 of a further 52 trawls had bycatch recorded. On TAN 9211, 96 of 104 tows had bycatch recorded, whereas after a crew change only 2 out of 58 tows had bycatch recorded. This is probably indicative of widespread inconsistency in the data" (p. 10).

Grove & Probert (1998) suggested improvements to the way benthic bycatch is recorded on fisheries research trips that can equally be applied to observer recording.

"Valuable information on the biology and ecology of benthic invertebrates is potentially available from trawl surveys of deepwater fishing. Such data have particular reference to studies of the environmental effects of trawling as well as to the distribution and structure of benthic assemblages and patterns of marine biodiversity in the New Zealand region" (p. 11).

It is suggested that invertebrate bycatch codes be revised to remove ambiguity and overlaps, and possibly provide more detailed information than at present. The authors consider the invertebrate codes currently used to be too broad to reveal anything but very gross trends in benthic invertebrate distribution. There is also a need to provide clear distinctions between no bycatch being *recorded* from a tow, and no bycatch being *caught* in the tow. They conclude that whilst there is a clear need to investigate the effects of trawling on benthic communities, there are opportunities to obtain useful invertebrate data from the trawl surveys themselves. All of the information and recommendations contained in this report can equally be applied to the scientific observer data in a following section of this review.

NIWA marine biology collection and database

The NIWA marine biology collection consists of more than 100 000 specimen lots of marine species from more than 10 000 seafloor locations in the New Zealand EEZ, surrounding sea area, Pacific Islands, and the Ross Sea (Gordon 2000). The collection is essentially an ecological one, organised taxonomically and includes the most diverse and largest sorted holding of many marine groups in New Zealand. There is also a large type collection comprising 652 holotypes and 1083 paratypes.

A significant portion of the NIWA biology collection (principally invertebrates) was sourced from the NZOI survey of shelf benthos beginning in the 1960s. The campaign ended in the 1980s and sampling since then has been largely opportunistic. The collection is still growing due to ongoing ad hoc research (MFish and PGSF funded), and important donations from scientific observers on board commercial fishing vessels (Nelson & Gordon 1997). Decades of taxonomic work remain with the potential for the collection of molecular information and other data on organismal size, chemical content, and reproductive state (D. Gordon, NIWA, pers. comm.).

Of the more than 8000 sampling stations, only 20% are in water deeper than 1000 m, which is over 70% of the New Zealand EEZ by area (Nelson & Gordon 1997). Important information about the samples in the marine biology collection is held in the biodiversity database. Information about each of the seafloor sampling stations includes coordinates, date, depth, gear type, organisms present, and any physical information also collected (sediment sample, temperature, photograph, etc. (Froude 2000). Table 2 shows the information contained in the database for two deepwater sampling stations – EO714 off northern Hawke Bay, and EO784 off the South Island west coast near Haast. Figure 2 shows the distribution of NIWA seafloor sampling stations over 1000 m water depth.

Figure 2 is one of the most important sources of information in this review, particularly in combination with Figure 1. Although it does not relay the actual biodiversity information, it indicates the locations from which NIWA has benthic biodiversity information. In this respect it also highlights areas that lack adequate coverage and could be targeted in future biodiversity investigations.

Information can be extracted from the database on request (to Don Robertson, NIWA, Wellington) with access and charges dependent on the source of the data and the intended use. It is possible to plot the distribution of individual species for any depth or any set of coordinates (D. Gordon, NIWA, pers. comm.), although not for sampling method. There are acknowledged problems with the database that prevent maximum gain being made of this valuable dataset, and NIWA is seeking to address these problems.

"Data and analytical challenges –

- Biodiversity data mainly non-quantitative presence–absence type
- Many biodiversity data not yet captured electronically
- Many biodiversity data not yet, or only partially analysed (e.g., identifications to family or genus only, few cluster analyses to ascertain relationships in assemblages)
- Many ancillary data (e.g., sediments) not yet digitised
- Existing databases need upgrading to accommodate new information fields and to permit linkages."

(from Gordon (2000) table 7: Summary of challenges facing New Zealand and Pacific Island nations in marine biodiversity assessment, living marine resources inventory, and censusing of marine life.)

Despite some obvious limitations related to the format of the database, the database is the most extensive and detailed source of information on benthic biodiversity in New Zealand. Inclusion of this information in the National Aquatic Biodiversity Information System would be a great advantage to fulfilling the goals the system is being developed to achieve.

Table 2: Information on stations E0714 and E784 held on the NIWA marine biodiversity database.

Station EO714 Sampled 02/03/1967
Lat: 39.3267 E Long: 178.3533 S Depth: 1284 m
Cruise: Hikurangi Benthos Gear: Medium Agassiz Trawl Ship: Taranui

Sediment and rock also recorded

Phylum	Class	Order	Family	Genus	Species
Cnidaria	Anthozoa	Actiniaria			
Cnidaria	Anthozoa	Scleractinia	Flabellidae	Flabellum	apertum
Mollusca	Gastropoda	Mesogastropoda	Ficidae	Thalassocyon	tui
Mollusca	Gastropoda			Pontiothauma	
Mollusca	Gastropoda	Stenoglossa	Turridae		
Mollusca	Gastropoda				
Mollusca	Bivalvia				
Arthropoda	Malacostraca	Isopoda			
Arthropoda	Malacostraca	Decapoda	Paguridae		
Echinodermata	Echinoidea				
Echinodermata	Stelleroidea				
Chordata	Osteichthyes	Gadiformes	Macrouridae		
Chordata	Osteichthyes				

Station: E784 Sampled 07/08/1967
Lat: 43.3833 E Long: 168.0833 S Depth: 1221 m
Cruise: South west slope Benthos Gear: Medium Agassiz Trawl Ship: Taranui
Sediment also recorded

Phylum	Class	Order	Family	Genus	Species
Protozoa	Granuloreticulosea	Foraminiferida	Schizamminidae	Julienella	zealandica
Porifera					
Cnidaria	Anthozoa	Gorgonacea	Isididae	Keratoisis	hikurangiensis
Cnidaria	Anthozoa	Pennatulacea			
Cnidaria	Anthozoa	Actiniaria			
Cnidaria	Anthozoa	Scleractinia	Flabellidae	Flabellum	apertum
Cnidaria	Anthozoa	Scleractinia	Fungiidae	Fungiacyathus	stephanus
Annelida	Polychaeta				
Mollusca	Gastropoda				
Mollusca	Bivalvia				
Mollusca	Scaphopoda				
Arthropoda	Crustacea				
Arthropoda	Crustacea				
Arthropoda	Crustacea				
Arthropoda	Crustacea	Thoracica	Scalpellidae	Smilium	acutum
Arthropoda	Malacostraca	Isopoda	Eurycopidae		
Arthropoda	Malacostraca	Isopoda			
Arthropoda	Malacostraca	Amphipoda			
Arthropoda	Malacostraca	Decapoda			
Bryozoa	Gymnolaemata	Cheilostomata	Bugulidae	Camptoplites	bicornis
Bryozoa				Riscodopa	parva
Bryozoa				Chevron	prestoni
Bryozoa				Trochosodon	mosaicus
Echinodermata	Echinoidea				
Echinodermata	Stelleroidea				

Te Papa Collection

"The marine collection at the Museum of New Zealand Te Papa Tongarewa holds the largest collection of marine fishes, marine mammals, seabirds and molluscs, and also has very large systematically arranged collections of other marine invertebrates and microalgae." (Nelson & Gordon 1997, p. 60b)

Roberts, C.D.; Paulin, C.D. (1997). Fish collections and collecting in New Zealand. *In* Pietsch, T.W.; Anderson, W.D. Jr. (eds), Collection building in ichthyology and herpetology. *American Society of Ichthyologists and Herpetologists Special Publication No. 3*: 207–229.

Like the NIWA marine biology collection, the collection of fish at Te Papa received major contributions from the 1954–80 NZOI sampling campaign. Several deepwater exploratory trips were carried out using local vessels from 1954 to 1957, returning many rare or new fish species, including the first specimens of *Hoplostethus atlanticus*, later to become the basis of the multi-million dollar orange roughy fishery. Numerous dredge collections were made from the Kermadec and subantarctic islands between 1974 and 1980 by Alex Black in conjunction with museum staff. Among the rich samples of deep benthic invertebrates were also some rare and cryptic fishes.

Government research and commercial deepwater fishing has continued to add new samples and species to the Te Papa collection since the end of the NZOI campaign. Although the collection continues to grow by about 30 species new to the New Zealand EEZ each year, it is acknowledged that New Zealand's fish fauna, especially at depths greater than 1500 m, is still incompletely known.

Information regarding the specimens housed in the Te Papa collection is held in *Te Kahui* – the database managing all the Museum's collections. Not all biological data are currently available, although it is intended to be given time (Froude 2000). There is no reporting mechanism specific to the deepwater aspects of the Te Papa collection other than occasional publications and monographs (see Stewart & Pietsch 1998, Sato et al. 1999, McMillan 1999). Information on the collection will be detailed in "The definitive guide to New Zealand fish species", a FRST funded project due for publication in 2005 (C. Roberts, Te Papa, pers. comm.). In addition to scientific publications, items from the collection also feature in "Something Fishy", a column in *New Zealand Fishing News*, and the "Museum Marine File" in *Seafood New Zealand*.