

CASE STUDIES AND REVIEWS

Benthic invertebrate bycatch from a deep-water trawl fishery, Chatham Rise, New Zealand

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ABSTRACT

1. Benthic invertebrate bycatch was collected during trawling for orange roughy (*Hoplostethus atlanticus*) at water depths of 662–1524 m on the northern and eastern Chatham Rise, New Zealand, in July 1994. Seventy-three trawl tows were examined, 49 from 'flat' areas and 24 from two groups of 'hills' (small seamounts). Benthos was recorded from 82% of all tows.

2. Some 96 benthic species were recorded including Ophiuroidea (12 spp.), Natantia (11 spp.), Asteroidea (11 spp.), Gorgonacea (11 spp.), Holothuroidea (7 spp.), and Porifera (6 spp.).

3. Cluster analysis showed the bycatch from flats and hills to differ significantly. Dominant taxa from flats were Holothuroidea, Asteroidea and Natantia; whereas taxa most commonly recorded from hills were Gorgonacea and Scleractinia. Bycatch from the two geographically separate groups of hills also differed significantly.

4. The largest bycatch volumes comprised corals from hills: Scleractinia (*Goniocorella dumosa*), Stylasteridae (*Errina chathamensis*) and Antipatharia (?*Bathyplates platycaulus*). Such large sessile epifauna may significantly increase the complexity of benthic habitat and trawling damage may thereby depress local biodiversity. Coral patches may require > 100 yr to recover.

5. Other environmental effects of deep-water trawling are briefly reviewed.

6. There is an urgent need to assess more fully the impact of trawling on seamount biotas and, in consequence, possible conservation measures.

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INTRODUCTION

In recent decades there has been increasing interest in the potentially wider impacts of commercial fishing, including changes to habitats and effects on non-target species (e.g. Parsons, 1992; Alverson *et al.*, 1994; Dayton *et al.*, 1995). Particular concerns have been raised with regard to bottom trawling where intensive fishing may result in significant alterations to the benthic environment and associated communities (De Groot, 1984; Hutchings, 1990; Messieh *et al.*, 1991; Jones, 1992). Understandably this interest has focused on shelf and shallow-water areas where major fishing grounds have traditionally been located. More recently, however, with the depletion of many inshore stocks, improvements in fishing technology and the development of a new international regime for the oceans, many deeper water fishing grounds have been exploited. New Zealand's EEZ includes extensive bathyal plateaux that support major deep-water fisheries. Important species include orange roughy (*Hoplostethus atlanticus*), hoki (*Macruronus novaezealandiae*) and oreos (Robertson, 1991; Sullivan, 1991). The rise of deep-water fisheries has not, however, been accompanied by research into environmental implications of deep-water fishing operations. In a review of environmental effects of trawling on the seabed, Jones (1992) considers that there is 'an urgent need to carry

out trawling impact studies in deeper water (> 500 m) since this is where studies indicate that effects could be severe and that any recovery may be measured in decades.' Environmental conditions and life-history characteristics of deep-sea benthic species suggest that the impacts of trawling and the course and duration of recovery may be very different from those seen at shelf depths. Fishers operating in New Zealand have noticed that the development of new deep-water grounds has been accompanied by a decline in invertebrate bycatch taken in trawls (Jones, 1992). Apart from anecdotal observations, little is known about the effects of intensive trawling on deep-water benthos and if these may have implications for the sustainable management of deep-water fisheries.

One of New Zealand's major deep-water fishing areas is the Chatham Rise, which has been fished commercially since 1978. The Chatham Rise is a relatively broad submarine high extending for some 800 km off central New Zealand to the east of the Chatham Islands; its crest lies at $\sim 43^{\circ} 30' S$. The Rise is generally flat-topped at 200–400 m, whilst to the north and south water depths increase to > 2000 m (Carter, 1980). The Subtropical Convergence (STC) overlies the Chatham Rise (Heath, 1985) and appears to be a zone of enhanced biomass and/or productivity (Vincent *et al.*, 1991; Probert and McKnight, 1993).

During a survey of orange roughy and associated fish on the northern and eastern Chatham Rise, the opportunity was available to collect and record the benthic invertebrate bycatch. This paper reports the results of that study. Historically, orange roughy fishing was initially confined mainly to flat areas, but with the development of suitable fishing techniques, the fishery now targets aggregations on small seamounts, usually referred to in the industry as 'hills' or 'pinnacles'. In this study fishing was carried out on both flat areas and on hills.

METHODS

Trawling was carried out from 1–15 July 1994 as part of a random stratified survey of orange roughy in the Chatham Rise area. A standard rough bottom orange roughy trawl was used with 600 mm diameter groundrope steel bobbins (*see* Clark and Tracey, 1992), similar to that normally used by commercial vessels trawling in this area. Seventy-three tows were made within a depth range of 662–1524 m. Twenty-four of the tows were short tows on hills in two areas: the 'Graveyard', a group of hills on the north Rise near 180° (742–1156 m), and in the North-east survey area east of the Chatham Islands (662–1127 m). The remaining 49 tows (ca. 3 nm) were from flat areas in the 'Spawning Box', north of the Chatham Islands, and North-east survey area (745–1524 m) (Figure 1).

At each station the trawl was observed being hauled in, emptied and prepared for the next tow. Once the catch had been chuted to the processing area and the trawl prepared for the next tow, the net and deck were examined carefully and any benthos retrieved. It was not feasible to examine the entire net without disrupting fishing operations. Some benthic specimens not retrieved from the deck were collected later from the processing area. Material was noted, preserved in isopropanol or deep-frozen, and retained for later examination and identification. Specimens collected are retained at the New Zealand Oceanographic Institute, Stations X481–X540.

Multivariate analysis was carried out using the PRIMER suite of programs (Plymouth Marine Laboratory). Hierarchical agglomerative clustering was undertaken using group-average sorting of Bray–Curtis similarity coefficients calculated from present/absence species data. Species that occurred in only one sample were not included in the cluster analysis. Five samples were not included in the analysis: X492, X501, X538 since they had no species in common with any other stations; and X494 and X495 since they grouped only to one another.

Significance testing between predefined groups of tows was examined using the ANOSIM (analysis of similarities) method, a non-parametric permutation procedure applied to the similarity matrix (Clarke and Greene, 1988). Hill tows were compared with flat tows, hill tows in the Graveyard area were compared with

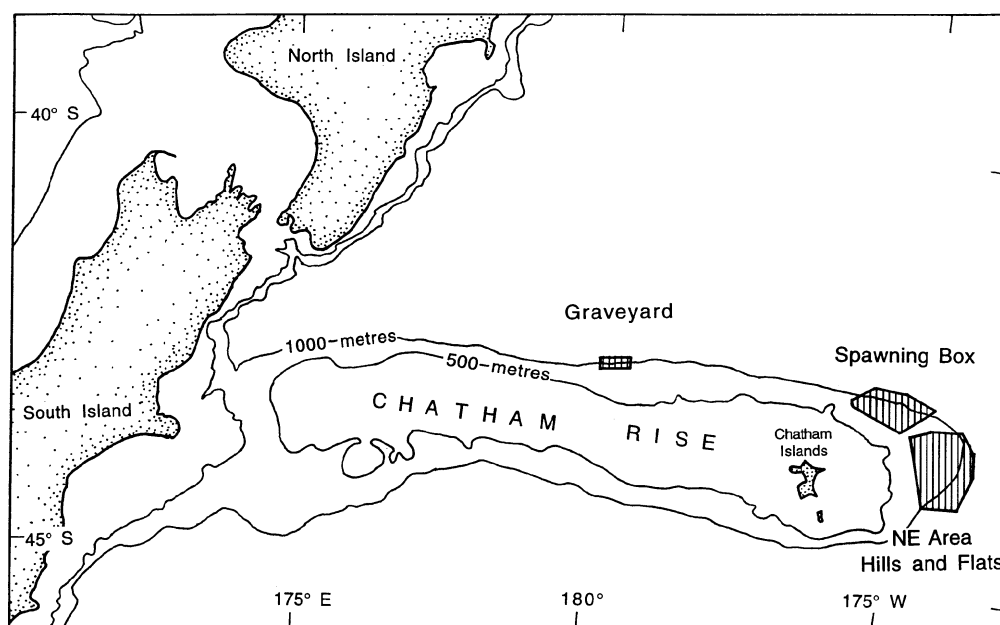


Figure 1. Location of the areas sampled: two hill areas (the Graveyard and the Northeast Hills) and two flat areas (Northeast Flats and Spawning Box).

those in the NE area, flat tows from different areas were compared, and flat tows from different depth groups were compared. For the latter, depth groups were as follows:

Depth Group	Spawning Box	North-east
1 (750–850 m)	506, <u>511</u> , 512, 516, 526, <u>527</u>	<u>507</u> , <u>525</u>
2 (850–950 m)	510, 513–515, 517, 519, <u>520</u> –523, 528	<u>505</u>
3 (950–1050 m)	518, <u>529</u> , <u>530</u> , 531, 542	<u>497</u> , <u>498</u>
4 (1050–1250 m)	<u>532</u> – <u>535</u> , (538), <u>539</u>	<u>496</u> , <u>499</u> , 500, 502, <u>503</u> , <u>504</u> , <u>508</u> , 509
5 (1250–1500 m)	536, 537, 540, 541	(495), (501)

Samples in parentheses were not used in the multivariate analysis. Underlined samples, chosen to match in terms of depth, were those used in comparing the two areas. Species that contribute most to significant dissimilarities between these groupings were determined using the SIMPER (similarity percentages) procedure of Clarke (1993).

RESULTS

Overall, benthic invertebrates were retrieved from 60 (82%) of the 73 trawl tows (Table 1). Benthic bycatch was recorded for 15 (63%) of the 24 hill tows, and for 45 (88%) of the 49 flat tows.

A wide range of invertebrate taxa were recorded in the benthic bycatch. Some of the crustaceans, in particular Mysidacea, Natantia and Polychelidae, may be pelagic rather than benthic. Specimens of polynoid polychaetes (abundant on Antipatharia), bryozoans, fish and cephalopods were also retained, but are not discussed here.

Table 1. Incidence of bycatch recorded from the survey areas

	Tows with bycatch	Total no. tows
Graveyard hills	7	9
Northeast hills	8	15
Hills total	15	24
Flats	45	49
Total	60	73

Table 2 indicates that the main invertebrate groups best represented were Asteroidea, Holothuroidea, Natantia, Gorgonacea and Hydroida. Certain groups were recovered only or largely from hill stations, notably Stylasteridae, Stolonifera, Gorgonacea, Scleractinia, Antipatharia, Galatheidae and Ophiuroidea. Groups that were conspicuously more common in flat tows were Pennatulacea, Natantia, Polychelidae, Asteroidea, Echinoidea and, in particular, Holothuroidea (taken at 53% of flat tows and at no hill tows).

Some 96 species were identified from the samples, though relatively few have been assigned scientific names. The most speciose groups were Gorgonacea and Ophiuroidea (12 species each), Natantia and Asteroidea (11 spp. each), Holothuroidea (7 spp.), and Porifera and thecate hydroids (6 spp. each).

A mean of 3.1 species per tow was recorded for all tows (including those without bycatch) (Table 3). Bycatch was recorded at only 8 of the 15 tows on the NE hills compared with 7 of the 9 tows in the Graveyard and this is reflected in the mean number of species per tow for these two areas. On average, the mean number of species per tow is similar for the hills and flats. Hill tows were, however, considerably shorter.

Table 2. Per cent occurrence of major taxa recorded from all tows, hill tows, and flat tows

Taxon	Total ($n = 73$)	Hills ($n = 24$)	Flats ($n = 49$)
Porifera	8.2	12.5	6.1
Hydroida	16.4	16.7	16.3
Stylasteridae	4.1	12.5	—
Stolonifera	2.7	8.3	—
Alcyonacea	1.4	4.2	—
Pennatulacea	8.2	—	12.2
Gorgonacea	24.7	37.5	18.4
Scleractinia	9.6	29.2	—
Antipatharia	8.2	25.0	—
Actiniaria	5.5	8.3	4.1
Zoanthidea	4.1	4.2	4.1
Mysidacea	4.1	4.2	4.1
Natantia	32.9	8.3	44.9
Galatheidae	4.1	12.5	—
Polychelidae	5.5	—	8.2
Brachyura	4.1	4.2	4.1
Paguridea	2.7	—	4.1
Bivalvia	9.6	4.2	12.2
Crinoidea	2.7	8.3	—
Asteroidea	39.7	20.8	49.0
Ophiuroidea	16.4	25.0	12.2
Echinoidea	6.8	4.2	8.2
Holothuroidea	35.6	—	53.1

Table 3. Numbers of species collected in the different survey areas

Area	Total length of tows (nm)	Mean no. species/tow	SD. No. species/tow	Number of species	No. species per nm towed
Graveyard	2.59 ^a	5.6	1.7	29	11.20
NE hills	5.89 ^a	2.1	2.9	28	4.75
Hills total	8.48 ^a	3.4	4.2	49	5.78
Flats	146.45	3.3	2.1	54	0.37
Total		3.1	2.9		

^aIndicates that the figure includes estimates based on other tows made on the same hill

From visual observations it was evident that the largest bycatch volumes occurred at hill stations and were dominated by cnidarians, in particular the scleractinian *Goniocorella dumosa* (Stations X483, X484, X486), the stylasterid *Errina chathamensis* (X484, X486, X487), and an antipatharian, *?Bathyplates platycaulus* (X488).

Several species were collected from both hills and flats. These included *Delectopecten forsterianum*, *Brisinga chathamensis*, *Ophiacantha yaldwyni* and *Araeosoma thetidis*. Species common to both hill areas were Hydroid sp. D, Stoloniferan sp., Gorgonacea sp. D, Gorgonacea sp. F, *Caryophyllia profunda*, *?Bathyplates platycaulus*, Galatheidae sp. B and *Ophiactis abyssicola*. Species most commonly recovered from the two hill and the two flat areas are listed in Table 4.

Results from the cluster analysis are shown in Figure 2. There are two main clusters, with the large group divisible into four smaller ones, B–E. The major group A comprises all the tows made on the hills. Apart from the outlier X481, clusters within Group A group the Graveyard tows plus one NE hill tow (X493), and another group comprising the remaining NE hill tows. Groups B–E are all flat tows but are not clearly separable due to the stepwise pattern of the linkages. Nevertheless, group E includes all the deeper flat tows (> 1019 m), apart from X497, X500, X502 and X537 which are in group B, and X499 in group D. Groups B, D and E include tows from both the NE flats and Spawning Box, but Group C tows are all from the Spawning Box.

ANOSIM tests showed significant differences in bycatch composition between the hill and flat tows ($R=0.307$, significance level <0.05%), and between hill tows from the Graveyard and those from the NE area ($R=0.513$, significance level 0.3%). (The significance level in ANOSIM tests refers to the percentage of random simulations which have a greater or equal test statistic (R , reflecting observed differences between groups, contrasted with differences within each group) than the test statistic for the actual groupings. Thus a significance level of 0.3% refers to the probability of the observed R value, in this case 0.513, occurring if the null hypothesis—no differences between hill tows and flat tows—is true.)

Results of an ANOSIM test to compare the different depth groups of the flat tows are shown in Table 5. A comparison of depth groups drawn from both the Spawning Box and NE area (the first two columns) indicates some significant differences between groups that are bathymetrically dissimilar. The various depth groups were not, however, evenly spread between the two flat tow areas, and a comparison was also made between depth groups using tows only from the Spawning Box (the last two columns). This shows a clearer distinction between dissimilar depth groups. However, ANOSIM testing of Spawning Box tows versus NE tows comparing only equal numbers of tows matched for depth, gave an R value of 0.088 and a significance level of 10.4%, suggesting some distinction between these areas unrelated to depth.

SIMPER analysis indicated that the species contributing most to the dissimilarity between groups of flat tows and hill tows were *?Bathyplates platycaulus*, *Novodinia novaezealandiae*, *Goniocorella dumosa* and Gorgonacea sp. F (more abundant in hills) and *Brisinga chathamensis* (more abundant in flats). These were the species found to be most widespread within each group of tows, while having a low occurrence in the other group. However, as discriminating species they were not highly diagnostic due mainly to their patchy occurrence within each group of tows (e.g. *?Bathyplates platycaulus* was found at 46% of hill tows and no flat tows; *Brisinga chathamensis* was found at 30% of flat tows and at one hill tow (8%)).

Table 4. Benthic invertebrate species most commonly recovered from the two hill areas and the two flat areas

Species	Higher taxa	No. stations at which recovered
Graveyard Hills (<i>n</i> = 9)		
<i>Goniocorella dumosa</i> (Alcock)	Scleractinia	5
<i>Novodinia novaezealandiae</i> (H. E. S. Clark)	Asteroidea	4
Gorgonacean sp. F	Gorgonacea	3
Gorgonacean sp. I	Gorgonacea	3
<i>Errina chathamensis</i> Cairns	Stylasteridae	3
Hydroid sp. D	Hydroida	2
Gorgonacean sp. G	Gorgonacea	2
<i>Caryophyllia profunda</i> Moseley	Scleractinia	2
Anemone sp. A	Actiniaria	2
cf. <i>Allostichaster</i> sp.	Asteroidea	2
<i>Ophiacantha rosea</i> Lyman	Ophiuroidea	2
Northeast Hills (<i>n</i> = 15)		
? <i>Bathyplates platycaulus</i> Totton	Antipatharia	5
Gorgonacean sp. B	Gorgonacea	2
Northeast Flats (<i>n</i> = 17)		
<i>Brisinga chathamensis</i> (McKnight)	Asteroidea	6
<i>Pasiphaea barnardi</i> Yaldwyn	Natantia	5
? <i>Pannychia moseleyi</i> Theel	Holothuroidea	4
Gorgonacean sp. A	Gorgonacea	3
<i>Lipkius holthuisi</i> Yaldwyn	Natantia	3
? <i>Virgularia</i> sp.	Pennatulacea	2
<i>Henricia aucklandiae</i> Mortensen	Asteroidea	2
<i>Plutonaster knoxi</i> Fell	Asteroidea	2
Holothurian sp. D	Holothuroidea	2
Spawning Box (<i>n</i> = 32)		
Holothurian sp. A	Holothuroidea	9
Holothurian sp. B	Holothuroidea	9
<i>Brisinga chathamensis</i> (McKnight)	Asteroidea	7
<i>Lipkius holthuisi</i> Yaldwyn	Natantia	6
? <i>Virgularia</i> sp.	Pennatulacea	4
<i>Benthoquetia integra</i> (Hedley) ^a	Bivalvia	4
<i>Araeosoma thetidis</i> (H. L. Clark)	Echinoidea	4
Hydroid sp. A	Hydroida	3
Hydroid sp. E	Hydroida	3
Gorgonacean sp. A	Gorgonacea	3
<i>Pasiphaea barnardi</i> Yaldwyn	Natantia	3
<i>Psilaster acuminatus</i> Sladen	Asteroidea	3
<i>Plutonaster knoxi</i> Fell	Asteroidea	3

^aEpizooic on Holothurian spp. A and B.

Graveyard hills were best distinguished from NE hills by *Novodinia novaezealandiae*, *Goniocorella dumosa* Gorgonacean spp. F and I, and *Errina chathamensis* (more in Graveyard samples) and *?Bathyplates platycaulus* (being representative of the NE hill samples).

Multivariate analyses were also carried out using the data aggregated to major taxa (which meant that no samples were omitted from the analysis). There were still significant differences between hills and flats ($R = 0.434$, significance = $< 0.05\%$), and between the Graveyard and NE hills ($R = 0.322$, 0.8% significance level). Taxa discriminating hills from flats were Gorgonacea, Scleractinia, Antipatharia and Ophiuroidea (more in hill samples); and Natantia, Asteroidea and Holothuroidea (more in flat samples). Taxa

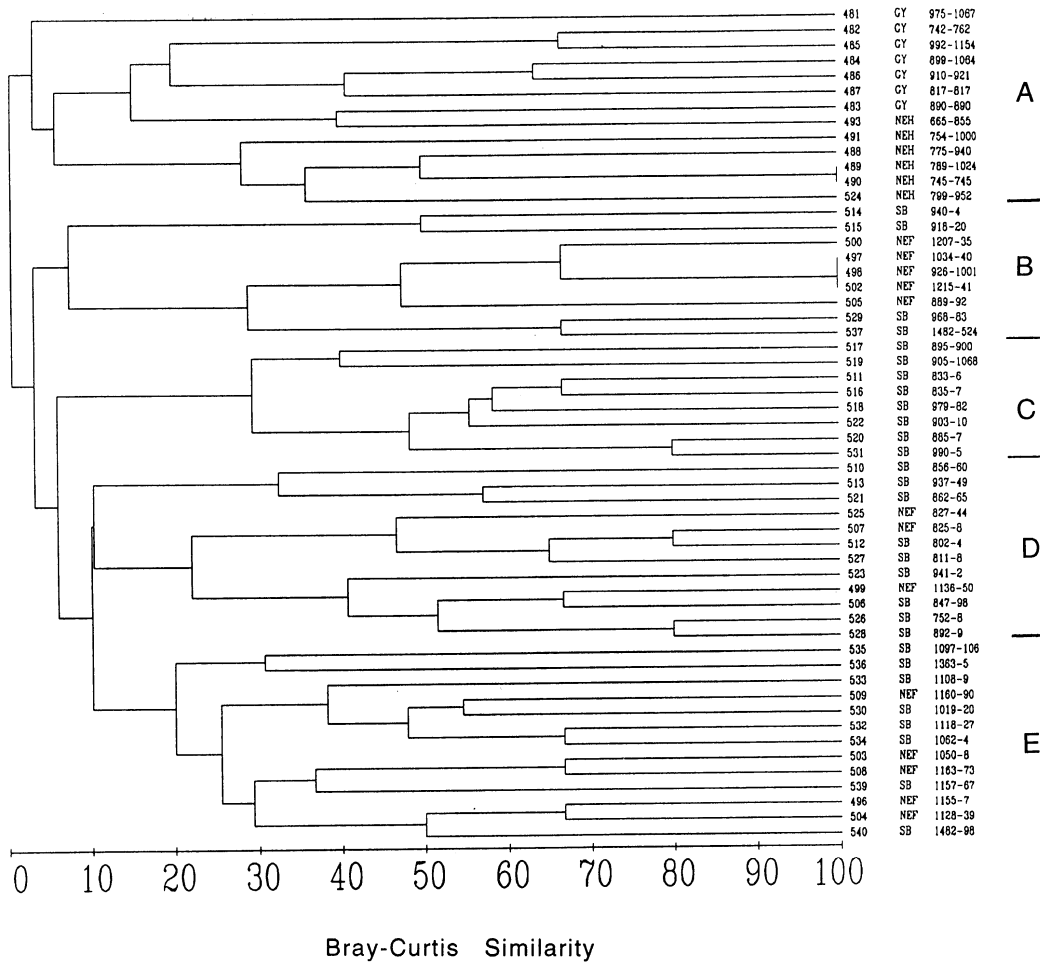


Figure 2. Dendrogram of hierarchical agglomerative clustering of the bycatch samples. Columns are: station number, location, and water depth (m). GY, the Graveyard; NEH, Northeast Hills; NEF, Northeast Flats; SB, Spawning Box.

Table 5. ANOSIM comparison of flat tows from depth groups 1-5 (as defined in Methods)

Depth groups compared	Spawning Box and NE Flat tows		Spawning Box tows only	
	R value	Signif. level (%)	R value	Signif. level (%)
1,2	0.043	24.6	-0.042	64.0
1,3	0.330	0.8	0.101	26.7
1,4	0.411	<0.05	0.261	4.1
1,5	0.316	4.8	0.265	6.0
2,3	0.145	6.6	0.058	30.6
2,4	0.325	<0.05	0.218	3.7
2,5	0.332	0.5	0.373	0.7
3,4	0.368	0.3	0.203	11.9
3,5	0.194	11.9	0.028	49.9
4,5	0.238	12.0	0.174	17.9

discriminating Graveyard from NE hills were Scleractinia, Gorgonacea and Stylasteridae (more in Graveyard); and Antipatharia, Ophiuroidea and Hydroida (more in NE hills).

DISCUSSION

Benthic community structure

Bycatch recorded in this study probably represents a very incomplete picture of the benthic community. Trawl gear used in the orange roughy fishery has large bobbins set along the ground rope which are likely to crush macrobenthic animals in their path. Smaller species may, however, be passed over by the trawl. Some body forms appear more susceptible to being taken than others. Our observations suggested that among the forms most likely to be retained are large upright species (e.g. black corals), spiny species that snag easily in the trawl mesh (e.g. stylasterids, brisingids), and large soft species that become pinched in angles of the trawl mesh (holothurians).

Nevertheless, the results do reflect some differences in benthic community structure, particularly between the bycatch taken on pinnacles and flats (Figure 2). Grove *et al.* (1995 unpublished report) record a similar distinction between flat tows and those from topographic features based on a more extensive analysis of the benthic invertebrate bycatch recorded from bathyal trawl fisheries surveys off southern and eastern New Zealand. McKnight and Probert (in prep.) found a strong bathymetric zonation of epibenthic community structure across the Chatham Rise, and in the present study there is evidence from flat tows that bycatch species composition changes with depth (Table 5).

There is some indication from this study that the two groups of pinnacles that were sampled have faunistic differences (Figure 2). However, in the absence of any comparative studies of the benthic communities of these features in the New Zealand region it is not known to what extent such a distinction might be expected. Seamounts appear to show significant levels of endemism and there is evidence that some populations on seamounts are morphologically and genetically distinct, indicating that they may be sites of high speciation (Rogers, 1994).

Exposed rock surfaces are relatively uncommon in the deep sea. One of the places where they occur is on seamounts where they can provide a major opportunity for the development of communities dominated by attached epifauna (Gage and Tyler, 1991). Seamounts in the Chatham Rise region permit the development of benthic assemblages in which large sessile species such as stylasterid and scleractinian corals form a distinctive and major component, although to date there have been few published records of such occurrences in the New Zealand region. Squires (1965) describes coral structures composed primarily of *Goniocorella dumosa* and *Desmophyllum cristagalli* at water depths of 366–541 m on the south flank of the Chatham Rise and from 320 m on the Campbell Plateau. Ralph and Squires (1962) mention large masses of *Goniocorella* from Cook Strait (350–550 m).

By contributing an important structural dimension, such species provide opportunities for many associated species, thereby creating patches of enhanced biodiversity. Colonies of *Goniocorella dumosa* provide niches for a diverse assemblage of organisms including other scleractinians, stoloniferans, sponges, stylasterids, bryozoans, polychaetes, ophiuroids, asteroids, gastropods, bivalves, anemones, and foraminiferans (Cairns, 1995). Comparable deep-water faunas have been described elsewhere. In his review, Jones (1950), for instance, recognized a 'boreal deep coral association'. The deep-water coral *Lophelia pertusa* forms banks that have been described from a number of localities in the northeastern Atlantic, along the continental margin and on prominences to depths of 1300 m (Zibrowius, 1980). Mature patches of *L. pertusa* on Rockall Bank may be 10–50 m across (Wilson, 1979a). The fauna associated with *Lophelia* reefs is of high diversity (Le Danois, 1948; Teichert, 1958; Jensen and Frederiksen, 1992), though not typical only of this habitat (Mortensen *et al.*, 1995). Similar in structure, but in shallower water, are the extensive banks and thickets of the scleractinian *Oculina varicosa* described as occurring on prominences at

depths of 50–100 m off central eastern Florida. Dense fish populations and diverse invertebrate assemblages are associated with deep-water *Oculina* reefs in the western Atlantic (Reed, 1980). Rocky outcrops on seamounts and guyots are similarly characterized by speciose assemblages dominated by suspension-feeders (Genin *et al.*, 1986; Kaufmann *et al.*, 1989).

Vulnerable taxa

In addition to exerting a major influence on benthic community structure, large sessile epibenthic species are also likely to be among taxa especially vulnerable to trawling impact as a result of commercial fishing. ICES (1994) assessed the potential vulnerability of organisms to trawling on a variety of criteria including life history characteristics, physical fragility/robustness, habitat and behavioural characteristics (e.g. whether epifaunal/infaunal/deep burrowing/rapid burrowing). It considered the most vulnerable organisms to be fragile long-lived species with infrequent recruitment, that may be nearly exterminated by a single passage of a trawl and which are unlikely to recover 'within a foreseeable future'. Likely to be included here are deep-water coral banks (e.g. *Lophelia*), as well as certain large gorgonians (*Paragorgia aborea*), sea pens (*Funiculina quadrangularis*, *Virgularia mirabilis*) and sponges (*Axinella polypoides*, *Geodia*, *Chondrocladia*). Wilson (1979b) suggested that trawling through a patch of *Lophelia pertusa* may enable the coral to increase its rate of colonization of the surrounding sea floor, but Jones (1992) has argued that repeated trawling could be expected to eradicate such coral patches.

There appear to be no estimates of growth rate and longevity for dominant epifaunal species occurring on the Chatham Rise pinnacles to indicate the likely period required for such communities to recover from trawling disturbance. Some indication may be provided from seemingly comparable species. For the coral *Lophelia pertusa* at 220–350 m on Rockall Bank, NE Atlantic, Wilson (1979b) estimated that the age of colonies 1.5 m in height may be 200–366 years. Antipatharians are typically relatively long-lived species with low rates of growth, fecundity, recruitment, and mortality (Grigg, 1989). *Antipathes fiordensis*, which occurs in shallow water (mostly < 100 m) in New Zealand fiords, has a very slow growth rate and colonies > 4 m in height (reasonably common) are estimated to be > 300 years old (Grange and Goldberg, 1993).

Other taxa vulnerable to trawling, such as some of the echinoderms, may also have important influences on benthic community structure. Holothurians, a major component of the bycatch from flat tows (Table 2), are important deposit feeders in many deep-sea communities, commonly dominating the invertebrate epifauna (Billett, 1991). As potentially indiscriminate croppers, large epibenthic deposit-feeding holothurians may promote deep-sea benthic diversity by suppressing competitive exclusion among the smaller benthos in the surface sediment (Dayton and Hessler, 1972). Echinoids were taken less frequently in the present study, though they are likely to be especially vulnerable to the passage of a trawl. Spatangids are known to be vulnerable to trawling (Bergman and Hup, 1992; Eleftheriou and Robertson, 1992). *Araeosoma thetidis* was the most commonly collected echinoid and, like many echinothuriids, is probably omnivorous (De Ridder and Lawrence, 1982). Brisingid asteroids were taken at many of the stations and may be important filter feeders in the community.

Other impacts on benthos

Frequent disturbance of benthos by trawling is likely to favour the more opportunistic recolonizers. Scavenging species may converge on benthos that is left damaged or disturbed on the sea bed as a result of trawling (Eleftheriou and Robertson, 1992; Kaiser and Spencer, 1994). At least in shallow-water areas intensive trawling may in the longer term be expected to alter population and community structure of benthos (Rumohr and Krost, 1991; Hall *et al.*, 1994). Scavengers of bathyal communities are likely to include lysianassid amphipods, isopods, decapod crustaceans, polychaetes (e.g. *Hyalinoecia*) ophiuroids and various fish (Britton and Morton, 1994).

The discarding of processing wastes at sea by fishing vessels has the potential to divert large amounts of organic material to surface and bottom scavengers. Among the primary benthic respondents to such organic enrichments are capitellid, spionid and dorvilleid polychaetes (Levin *et al.*, 1994). The dumping of hoki wastes on the continental slope off the South Island west coast has raised concerns that it could locally deplete seabed oxygen levels (Livingston and Rutherford, 1988). Preliminary assessment of the impact on the benthos of dumping an estimated 50 000 t of hoki offal per fishing season off the South Island west coast confirmed that wastes reached the sea floor (<800 m) in sufficient quantities to alter the benthic community composition (Grange, 1993). Disturbance of the seabed from the passage of a trawl is likely to provide a similar opportunity for infaunal opportunists recolonizing a newly created patch (Desbruyères *et al.*, 1980; Grassle and Morse-Porteous, 1987).

Modelling results indicate that sediment resuspension by trawls can make a sizeable contribution to the total suspended solid load over heavily trawled areas at shelf depths (Churchill, 1989; Riemann and Hoffmann, 1991). Fine-grained sediments at bathyal depths are likely to be readily resuspended by trawling, but whether this is likely to greatly exceed natural resuspension and significantly impact on benthic species, particularly suspension feeders, in the study area is not known. Resuspension and smothering has been identified as a potentially important effect of deep-sea mining (Thiel, 1992).

Benthos–fisheries interactions

It has long been known that fish often aggregate on seamounts. In most cases this is probably because diurnally migrating plankton, entrapped as they are advected over the seamount, become a source of prey. There may, however, be other reasons for such aggregations. For some fish species, seamounts may play a role in reproduction and life history, in behavioural ecology, or because of interactions with benthos (Rogers, 1994). For the mid-slope demersal fish community of New Zealand and southeastern Australia, major aggregations are known to be associated with topographic features such as pinnacles (e.g. Koslow *et al.*, 1994). But whether there may be significant benthos–fisheries interactions in such communities is not known. If this were to be the case, then damage to the benthos could impact on the sustainability of fish populations. It is well known from studies of shallow-water environments that some sessile species can significantly enhance structural complexity of benthic habitat, in some cases by contributing reef-like formations. Bryozoan reefs can, for instance, provide opportunities for many associated invertebrates, and in turn may be important to fish, including juveniles of commercial importance (Probert *et al.*, 1979; Bradstock and Gordon, 1983). Sainsbury (1988) reported an alteration to the demersal environment of the Australian northwest shelf due to trawling, notably a reduction in epibenthic fauna (mostly sponges, alcyonarians and gorgonians) and a decline in the trawl catch of fish (e.g. *Lethrinus* and *Lutjanus*) associated with these benthic habitats.

CONCLUSIONS

Seamounts can exert a strong influence on large-scale patchiness of deep-sea benthos by providing opportunities for the relatively large-scale development of faunas dominated by sessile animals in an environment otherwise characterized by fine-grained sediments. The composition of benthic faunas associated with seamounts in the New Zealand region has yet to be assessed in any detail. In terms of marine biodiversity of the New Zealand region, seamounts may prove very significant for certain taxa. Stylasterids, for instance, prefer deep shelf and slope depths of offshore submarine ridges and seamounts, and New Zealand's stylasterid fauna is the most diverse known (Cairns, 1991). Seamounts are also likely to be important for their pelagic populations; fish aggregations were mentioned earlier. Some cetacean species concentrate at steep topographic features of the seafloor (Hui, 1985). (Trawler operators often sight sperm whales at pinnacles on the Chatham Rise.) Haney *et al.* (1995) reported larger aggregations of

procellariiform seabirds at a seamount in the North Pacific compared with the seabird community away from the seamount, which they attributed to changes in the abundance and/or behaviour of potential prey organisms from the deep-scattering layer.

To date there has been little interest worldwide in the conservation of deep-sea habitats (Angel, 1992). The UN Convention on the Law of the Sea (United Nations, 1983) includes general articles on the conservation of the living resources of exclusive economic zones and the high seas (Articles 61 and 119 respectively). Burnett *et al.* (1992) consider that conservation measures may be appropriate in the case of certain deep-sea environments that are small in extent, host endemic species, and are readily changed, such as hydrothermal vent fields, cold seeps, and ocean trenches. For such reasons there is a case for examining options for the conservation of seamounts. It has recently been suggested that an area of deep newly mapped seamounts off southern Tasmania be set aside as a marine reserve (Koslow and Exon, 1995). New Zealand's Marine Reserves Act 1971 has so far been used to establish 13 marine reserves, but the legislation applies only to the territorial sea (< 12 nm offshore). The country's Territorial Sea and Exclusive Economic Zone Act 1977 (Section 27) does provide for measures for the protection and preservation of the marine environment of New Zealand's Exclusive Economic zone, but has never been used to set aside areas which could be protected from deep-water trawling. Recent fisheries legislation in New Zealand does, however, recognize the potentially wider environmental effects of fishing. The Fisheries Act 1996 requires the following environmental principles to be taken into account (Section 9):

- '(a) Associated or dependent species should be maintained above a level that ensures their long-term viability;
- (b) Biological diversity of the aquatic environment should be maintained;
- (c) Habitat of particular significance for fisheries management should be protected.'

In a recent UK report on fish stock conservation and management, the House of Lords' Select Committee on Science and Technology (1996) recommends a 'cautious approach to the development of fisheries on deep-water fish stocks and, in particular, . . . that gear capable of damaging the deep-water environment should be avoided.' Certainly for seamount biotas there is an urgent need to assess more fully the issue of trawling impact and possible conservation measures.

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