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EXECUTIVE SUMMARY

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In 2001 the Ministry of Fisheries contracted NIWA to study the macrofaunal bycatch of commercial oyster dredging in Foveaux Strait. The objectives were: to sample the bycatch of dredge samples from a broadly representative series of stations in Foveaux Strait; to sort, identify to the lowest possible taxon, and catalogue numbers of individuals; and to characterise sub-areas of Foveaux Strait by macrofaunal groupings and fishing history.

Macrofaunal bycatch was sampled during the biennial stratified random dredge survey estimating the size of the oyster population of Foveaux Strait. Fishers designated boundaries for Commercial, Exploratory, and Background strata. The bycatch was sampled from 60 randomly selected stations: Commercial, Exploratory, and Background areas were sampled with four strata in each, and five sample stations in each stratum.

At least 190 putative species were identified in the macrofaunal bycatch representing 82 families and 12 phyla.

Pair-wise comparisons of Bray-Curtis similarity measures (taken at family level and scored as either present or absent) between sampling strata indicated that the macrofaunal bycatch assemblage within Commercial and Exploratory strata were 60% similar, whereas those within the Background strata were only 38% similar. The macrofaunal assemblages in the Commercial and Exploratory strata were on average 41% dissimilar, whereas those of the Background stratum were 54 and 52% dissimilar from the Commercial and Exploratory strata respectively.

Similarity analysis also revealed characterising taxa for each of the strata. For the Commercial strata these were the Balanidae, Mytilidae, Ophiodermatidae, Ostreidae, and Pyuridae; for the Exploratory strata, the Balanidae, Calyptraidae, Mytilidae, and Ostreidae; for the Background strata, the Eunicidae, Mytilidae, Ostreidae, Paguridae, Pyuridae, and Styelidae.

The results appear to support the general predictions made from the fishers' strata designation (supported by the qualitative analysis of the fishing effort record) of the likely assemblage composition in Foveaux Strait.

In order to realise the full potential of macrofaunal bycatch data from the present survey, all samples should be identified to species level or putative species level before additional statistical analysis. Before further bycatch surveys are undertaken, a standard scientifically robust and logistically practicable macrofauna bycatch sampling protocol should be developed for the Foveaux Strait oyster fishery. Future surveys should consider specifically identifying and defining the extent of habitat of particular significance for oyster fishery management.

1. INTRODUCTION

1.1 Overview

The effects of fishing activity have frequently been demonstrated, to the extent that it is general accepted that fishing has an impact in the marine environment (see Jennings & Kaiser 1998, Hall 1999, Moore & Jennings 2000, Kaiser & de Groot 2000, Jennings et al. 2001). One aspect of the impact of fishing that has received scientific attention is the evaluation of fishery bycatch (e.g., see review by Andrew & Pepperell 1992). Bycatch consists of all species caught that were not the target of the fishery; the incidental bycatch that is valuable is landed, and the bycatch that is not, is discarded (Alverson 1997). Studies of bycatch have principally focused on determining the effects of fishing on non-target fish (e.g., Ramm et al. 1990, Clark et al., 2000, Francis et al. 2000) or individual species, particularly large, rare, slow growing 'charismatic' fauna (e.g., birds, turtles, seals) (Dayton et al. 1995, Baird 2001). Fewer studies have concentrated on the composition of the benthic macrofaunal assemblage of the bycatch that is associated with specific target species (e.g., Gray et al. 1990). However, the latter type of studies have provided not only useful data on the composition of benthic macrofaunal assemblages (e.g., Watson et al. 1990), but also indications of change in composition that might be attributable to longer-term effects of fishing (e.g., Harris & Poiner 1990). In New Zealand, an examination of macroinvertebrate bycatch composition from different habitats fished for orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise first served to raise concerns about the possible impact of bottom fishing on the diversity of potentially vulnerable seamount assemblages (Probert et al. 1997). Since then, the macrofaunal bycatch of New Zealand fisheries has received some attention (Grove & Probert 1998, Cryer et al. 2000, 2002).

The seafloor of Foveaux Strait in southern New Zealand has been dredged for the oyster *Ostrea chilensis* for 130 years. Initial dredges were small and light, but between 1968 and 1970, following catch rate decline, fishers developed a heavy dredge (400 kg) that can be towed in any direction regardless of tidal currents or alignment of habitat, as well as penetrating more deeply into the substrate (up to 10 to 20 cm). These dredges can potentially catch or damage all macrofauna in their path, although their low retention of oysters (16% efficiency in retaining oysters; Doonan et al. (1994), suggests not all macrofauna are retained as bycatch. Oyster vessels follow a standard fishing procedure. They tow two 3.35 m-wide dredges, simultaneously launching them as the vessel steams up into the tide, towing them around in a circle down-tide, and hauling them as the vessel turns up-tide again. The steel rings of the catch bag belly effectively retain objects greater than 51 mm. The dredge catch is thoroughly washed by dunking the dredge bag up and down in the water to remove sediment and smaller organisms before the dredge is emptied and the contents sorted. Only oysters of marketable size (over 58 mm) are retained, the remainder of the dredge contents, the bycatch, and undersized oysters, is discarded at sea. The fate of the discarded bycatch has not been determined.

The seafloor of Foveaux Strait has probably been disturbed continuously by fishing longer and more intensively than any other marine environment in New Zealand. The scale and nature of these fishing-induced changes cannot be determined because of the scarcity of fine spatial and temporal data on benthic habitat and fishing effort over the whole fishery area, or disentangled from habitat changes bought about by environmental factors. Cranfield et al. (1999) inferred modification and changes in the distribution of seabed habitat and associated macrofauna from details of dredging history.

Although surveys of the oyster populations have been undertaken frequently, almost since the Foveaux Strait fishery began (e.g., Hunter 1906), and qualitative assessments of the bycatch fauna occasionally reported (e.g., Stead 1971a, Cranfield et al. 1991, Doonan & Cranfield 1992), the macrofaunal bycatch of the fishery has been described only once. This qualitative description by Fleming (1952) identifies the macrofauna landed during a day's commercial dredging for oysters at a location that at that time had been dredged for only two months. Fleming's description of the patchy nature of the habitat fished and the domination of the sample by epifaunal organisms allows us to recognise the presence of a biogenic reef. Associations of epifaunal bryozoans, ascidians, sponges, and molluscs can form structures known as 'biogenic' or 'epifaunal' reefs (sometimes referred to as 'bioherms'). Sidescan sonar records and fishing records of early fishers suggest that biogenic reefs originally covered much of the floor of Foveaux Strait (Cranfield et al. 1999). Oysters were a component of the biogenic reef habitat, so reefs containing commercially viable densities of this species were specifically targeted by oyster fishers. Biogenic reefs have been substantially modified by oyster dredging, and all were thought to have been removed by 1992, by which time dredging had extended to the limits of oyster distribution (Cranfield et al. 1999). These biogenic reefs consisted of aggregated patch reefs (extending up to 1 m above the seabed, and ranging in diameter from metres to 10s of metres) that formed long linear structures, generally 500 m wide and kilometres long. These reefs were aligned with the direction of the tidal currents (Cranfield et al. 1999). The bryozoan *Cinctipora elegans* formed the structural framework of these reefs and a wide variety of tunicates and other organisms settled within this structure and bound it together more strongly (see Willan 1981). Bycatch of oyster fishing in particular localities in the late 1970s frequently consisted of species typical of this habitat (Cranfield et al., 1999), but such bycatch has become rare (Robjohns 1979, fishers' pers. comms.).

1.2 Objective

This report covers objective 3 of the project 'Foveaux Strait oyster stock assessment' (MFish contract OYS2001/01). The objective was "to identify and count macrofauna collected during a (biennial) dredge survey" of the size of the oyster population in Foveaux Strait. The objective has three key activities.

- To sample the bycatch of dredge samples from a broadly representative series of stations in Foveaux Strait.
- To sort, identify to the lowest possible taxon, and catalogue numbers of individuals.
- To characterise sub-areas of Foveaux Strait by macrofaunal groupings and fishing history.

2. METHODS

2.1 Study site

Foveaux Strait separates the South Island and Stewart Island of New Zealand (Figure 1), and is about 80 km long and 23–53 km wide. The seafloor is principally alluvial gravels, locally overlaid with sand, and slopes gently from 50 m deep in the west to 20 m in the east. Islands and reefs extend across the shallow eastern entrance from Paterson Inlet (Stewart Island) northwards (Cullen 1967). Foveaux Strait is a high tidal current and wave energy environment. Tidal streams set to the east on the rising tide and to the west on the falling tide. The velocity of the tidal streams does not generally exceed 80 cm/s, but may reach 120 cm /s during spring tides in the eastern entrance and between the islands of the strait. Long-period waves originate from the west and southwest, and when the prevailing direction of storm swells and tidal flow coincide, bottom orbital velocities are very high (Cullen 1967). Foveaux Strait has a high phytoplankton standing stock (Bradford et al. 1991), and with the strong currents gives rise to ideal conditions for filter-feeding benthic fauna and diverse macrofaunal assemblages.

2.2 Survey design

The Foveaux Strait oyster population/*Bonamia* survey of 2002 followed a stratified random sampling design determined for oyster/*Bonamia* abundance/incidence (Michael et al. 2004), to which the macrofaunal bycatch survey was logistically constrained. The strata boundaries were determined by fishers from their experience of the previous fishing season and analysis of logbook data. Fishers designated Commercial (C) and Exploratory (E) strata for the fishery survey on this basis. Commercial strata included areas that fishers considered from their fishing in the previous oyster season (March–August 2001) would support commercial fishing in 2002. Exploratory strata represent areas in which fishers believed that oyster density was rebuilding and which would probably support commercial fishing in the future. A third division, Background strata (B), includes all the area remaining in the fishery and parts of this area have been occasionally fished in the past for the oysters that occur in widely dispersed small patches. Each of these strata were subdivided into a number of substrata (Figure 2a) to ensure a more even spread of sampling throughout Foveaux Strait. The allocation of sampling stations within each substratum was related to the expected density and variance of oyster catches and the area of the stratum. Commercial, Exploratory, and Background strata were allocated 110, 52, and 48 stations respectively (Figure 2b). Randomly selected station positions were generated for each stratum with exclusion zones in order for sample tows to avoid crossing one another or stratum boundaries (0.3 nautical mile from any other tow, 0.1 nautical mile from any stratum boundary). Due to time/budget-resource constraints, five replicate samples of macrofauna bycatch (first five random station allocations) were taken in each of four strata that represented the three main sampling strata (Figure 2b, 2c).

2.3 Fishing history

Stratification of the survey was based on designated fishery areas, Commercial, Exploratory, and Background (see section 2.2). This stratification was not based on fishing history. However, indicative fishing history of the strata used in the study can be described qualitatively using effort data from the Foveaux Strait oyster fishery. The standard catch effort and landing returns (CELRs) for the fishery assign fishing effort to 16 broad statistical areas that are inconsistent with the strata sampled in the present study. Thus, fishers' logbook data, that define more precisely where fishing took place, are the only means by which fishing history can be evaluated for the specific areas sampled for benthic bycatch. Logbooks have been kept by fishers only since 1996, when the fishery reopened after the closure caused by the *Bonamia* outbreak. However, before 1999 relatively few fishers filled in logbooks and therefore only data between 1999 and 2001 (when 34, 38, and 41% of fishers completed logbooks respectively) can be reasonably extrapolated to represent the effort of the oyster fishing fleet. Fishers recorded in their logbooks the positions (± 500 m) of oyster patches that they fished and the number of dredge tows (effort) on each patch (Dunn et al. 2000). The position of each patch fished is recorded from Global Positioning System coordinates and these positions allow tows to be readily assigned to the specific strata of the survey. The effort for each stratum was multiplied up to represent the total number of vessels fishing in a particular year (assuming vessels that filled out logbooks were representative of those that did not).

2.4 Sampling methods

The 60 bycatch stations were sampled from an oyster vessel towing a commercial oyster dredge 3.35 m wide, with a catch bag with an effective mesh size of 51 mm. The tow method followed in the survey, a straight-line tow of 370 m down-tide, differs from the standard commercial towing method that tows in a circle (but covers the same area). Tows began from the selected station positions, identified by the vessel's Differential Global Positioning System. Three stations (44, 168, 171) could not be sampled because of foul ground and their positions were reallocated within their original strata. Dredges were landed unwashed (commercial dredges are washed) to reduce the loss of small benthic fauna after the dredge fullness was estimated by eye. The contents of the dredge were photographed with a digital camera as the dredge was emptied on to the sorting bench. The catch was divided into four portions and one of these was randomly allocated from each tow as a subsample for determining the nature of the bycatch. The bycatch sub-sample was further subdivided into four to produce a volume of sample that could be manageably transported, yet presumably was large enough to include most of the rarer species in the bycatch. Thus the proportion of the bycatch retained as a sample represents about 6% of the total dredge catch. Three stations did not conform to this standardisation (148, at which the catch was very large so that only about 3% was logistically practicable to transport; stations 150 and 170, at which the catch was so small that 100% was taken). Oysters were first sorted from the sample to count them and then either returned to the sample immediately or kept separate for later addition. Thus the sample taken represents the macrofaunal assemblage rather than bycatch alone. The volume of the sample was quantified, then the sample was bagged and labelled. On return to port, samples were packed in cardboard cartons, frozen, and transported to the laboratory.

The sampling was completed in 15 sampling days between 16 October and 3 November 2001. Most of the stations were sampled in light wind conditions (wind force 3 on the Beaufort scale) and all dredge tows were landed less than 80% full (over which a dredge is considered to have become saturated). Thus, sea conditions and dredge saturation are thought likely to have had minimal effects on the effectiveness of the sampling (commercial fishing frequently occurs in rougher weather conditions).

2.5 Laboratory analysis

The frozen samples were allowed to defrost for about 24 h, and then washed on a 6 mm sieve with seawater to separate the fauna and remove adhering sediment. Fauna retained on the sieve were transferred to white trays for sorting into major taxa by eye. In the time available, taxa were then identified (and enumerated if non-colonial) to lowest possible taxonomic level or identified as putative species. Identified fauna were preserved and stored in formalin, alcohol, or frozen as appropriate. Digital photographs of example specimens of most taxa were taken for reference.

2.6 Data analysis

For faunal assemblages to be compared robustly, comparisons are made at the lowest taxonomic level to which all fauna can be identified. In this study, comparisons of macrofaunal assemblages between strata have therefore been made at family level using presence or absence rather than numbers of individuals. Taxa for which it was not possible to assign identification at family level were omitted from the analysis. Analysis of assemblage data at the family level has consistently proved sufficient to identify natural spatial variation and patterns of disturbance in marine macrofauna assemblages (e.g., Warwick 1993, James et al. 1995). Only one of the stations for which subsampling had not complied with the standard practice was not included in the analysis (Station 148). We do not believe that the presence/absence record of the one or two taxa sampled at the two stations (Stations 150, 170) for which the whole catch was retained will affect the analysis.

The strata assemblages were characterised using the statistical programme SIMPER (Similarity Percentages). This routine, using the family presence/absence matrix, first calculates the Bray-Curtis similarity between samples before determining the average similarity within a sampling stratum ($\overline{S}$) and the average dissimilarity between sampling strata ($\bar{\delta}$). The average contribution that each family makes to the similarity or dissimilarity is also calculated ($\bar{S}_i$, $\bar{\delta}_i$). The standard deviation of these values (SD($\bar{S}_i$) or SD($\bar{\delta}_i$)) is a measure of the consistency of the family's contribution to the observed similarity (within a stratum) or dissimilarity (between strata). If the $\bar{S}_i$ or $\bar{\delta}_i$ is large and the SD($\bar{S}_i$) or SD($\bar{\delta}_i$) small (and thus the ratio $\bar{S}_i$/SD($\bar{S}_i$) or $\bar{\delta}_i$/SD($\bar{\delta}_i$) is large – or at least more than 1.0), then the family is deemed useful for characterising a stratum or discriminating between strata. SIMPER is one of the programmes contained within the PRIMER statistical software (Plymouth Routines in Multivariate Ecological Research, see Clarke & Warwick (2001), and Clarke & Gorley (2001) and references therein).

3. RESULTS

3.1 Fishing history

For the period examined, the Commercial strata on average could have experienced six to nine times the fishing effort ($\bar{x}$ = 11 369 tows per year) of the Background ($\bar{x}$ = 1754 tows per year) and Exploratory ($\bar{x}$ = 1226 tows y^{-1}) sampling strata respectively. This effort was not distributed evenly. The Commercial strata received relatively moderate fishing in 1999 (3547 tows y^{-1}) followed by relatively heavy and consistent fishing effort in 2000 and 2001 (15 035 and 15 526 tows y^{-1} respectively). The Exploratory strata also received relatively moderate effort in 1999 (3127 tows y^{-1}), but, conversely, in the years 2000 and 2001 these strata were subjected to a marked decreasing level of relatively light fishing effort (487 to 63 tows y^{-1} respectively). The Background strata were subjected to consistent, relatively moderate fishing in 1999 and 2000 (2530 and 2400 tows y^{-1} respectively), followed in 2001 by relatively light fishing (332 tows y^{-1}).

3.2 Macrofauna bycatch

For the 60 stations sampled, at least 190 putative species, representing 82 families within 12 phyla, were identified. For the taxa that could be enumerated, the maximum number of individuals recorded in a station sample was 474.

Macrofauna sampled from stations in the Commercial strata showed a 60% similarity in assemblage composition. Samples from within these strata were principally characterised ($\bar{S}_i$/SD($\bar{S}_i$) all 5.05) by taxa belonging to the families Balanidae, Mytilidae, Ophiodermatidae, Ostreidae, and Pyuridae. These families were present at all stations within the Commercial strata and together accounted for nearly one-third of the average similarity observed (each contributed 6.24%) (Table 1a). Macrofauna sampled from stations in the Exploratory strata also showed a 60% similarity in assemblage composition. Samples from within these strata were principally characterised ($\bar{S}_i$/SD($\bar{S}_i$) all 3.08) by taxa belonging to the families Balanidae, Calyptraidae, Mytilidae, and Ostreidae. These families were present at all stations within the Exploratory strata and together accounted for one-fifth of the average similarity observed (each contributed 5.12%) (Table 1b). Macrofauna sampled from stations in the Background strata exhibited a 38% similarity in assemblage composition. Samples from within these strata were characterised ($\bar{S}_i$/SD($\bar{S}_i$) all over 1.0) by taxa belonging to the families Eunicidae, Mytilidae, Ostreidae, Paguridae, Pyuridae, and Styelidae. These families all had a high (over 0.75) average station presence within the Background strata and together accounted for nearly one-third of the average similarity observed (each contributed over 4.5%). The Ophiodermatidae had on average the highest station presence (0.90) in this stratum, but the inconsistent contribution to the similarity observed resulted in it not being a useful characterising family ($\bar{S}_i$/SD($\bar{S}_i$) = 0.48) (Table 1c).

Formal pair-wise comparisons of the macrofauna assemblage composition of each of the sampling strata indicated that the Commercial and Exploratory strata are on average 41% dissimilar, whilst the Background strata exhibit a 54% and 52% average dissimilarity between the Commercial and Exploratory strata respectively. No families contribute more than 2.6% to the dissimilarities observed between any of the strata comparisons (Table 2). Echinometridae and Bitectiporidae were discriminating families ($\bar{\delta}_i / SD(\bar{\delta}_i) = 1.22, 1.00$) for the Commercial and Exploratory comparison (Table 2a), whilst the Fissurellidae and Muricidae both serve to discriminate ($\bar{\delta}_i / SD(\bar{\delta}_i) > 1.0$) between the Exploratory and Background strata macrofauna assemblages (Table 2b). No families were found to be useful for discriminating ($\bar{\delta}_i / SD(\bar{\delta}_i)$ all < 1.0) between the dissimilarity observed between the Commercial and Background strata (Table 2c).

4. DISCUSSION

The evidence of change in Foveaux Strait biogenic reefs through the fishing history presented by Cranfield et al. (1999) suggests that no unmodified biogenic reefs are likely to remain in any fished area. Hence the benthic macrofaunal assemblage of any area of the strait is unlikely to have the same composition recorded for unfished reefs. Cranfield et al. (2001) inferred that biogenic reefs can regenerate in the absence of fishing. The macrofauna assemblage composition on regenerating reefs is thus likely to reflect an ecological succession with the increasing length of time that the seabed has not been disturbed by oyster dredging, as well as the propinquity of sources of recolonising propagules (Cranfield et al. 2001). The macrofaunal assemblages of areas that have only ever been lightly fished, or have not been fished for some time, are likely to have a composition that approaches that of an unmodified biogenic reef. Furthermore, because of the heterogenous distribution pattern of biogenic reef habitat, it is possible that some small patches of unmodified reef will remain in areas that have received little fishing pressure. The macrofaunal assemblage of areas that contain isolated patches of unfished biogenic reef are likely to have compositions reminiscent of both biogenic reef and other seabed habitats. Thus, it is reasonable to expect that the bycatch macrofaunal assemblage sampled in each of the main categories of strata will be characterised by different taxa, and that differences in assemblage composition between strata will be consistent with the likely impact of historical oyster fishing on biogenic reefs. Specifically, the Commercial and Exploratory strata will both contain taxa indicative of a biogenic reef macrofaunal assemblage modified by fishing activity. Assemblages sampled in the Exploratory strata, however, are likely to have regenerated sufficiently for their composition to be more similar to that of unmodified biogenic reef assemblages in the more consistently and heavily fished Commercial strata. Background strata macrofauna assemblages are expected to have the most variable taxa composition, as the seabed will consist of a greater range of habitats, including unmodified and variably modified biogenic reef. Thus, Commercial and Exploratory macrofaunal assemblages will be more similar to one another, whilst the Background strata assemblage will be distinctly dissimilar from them both.

The macrofauna bycatch assemblages of the three sampling strata, based on fishing history, were formally characterised and discriminated using multivariate analyses. No bryozoan families were found to characterise any of the strata sampled. Thus, as predicted, macrofaunal assemblages (for each stratum as a whole) in Foveaux Strait do not reflect an unmodified state such as that recorded for an unfished biogenic reef in nearby Paterson Inlet (Stewart Island) (Willan 1981), or the 'nearly virgin' reef sampled by Fleming (1952). Such biogenic reefs were characterised by bryozoans, particularly the structurally important species *Cinctipora elegans* (Willan 1981). Examination of the individual station records indicates that no *C. elegans* occurred in bycatch samples from the Commercial strata, whilst living colonies occurred at only a quarter of both Exploratory and Background strata stations. Not surprisingly, assemblages of all strata were characterised by the presence of Ostreidae. The only representative of this family found in the survey was *Ostrea chilensis*, the target of the

Foveaux Strait oyster fishery, which was found throughout the whole of the survey area both in this and in previous studies (Cullen 1962, Stead 1971a). The bycatch assemblage of Commercial strata is characterised by mytilid bivalves (e.g., *Modiolus areolatus, Modiolarca impacta*) and pyurid tunicates (e.g., *Pyura* spp.), taxa that contribute to the formation of biogenic reefs in Foveaux Strait through the binding capabilities of their byssus threads and tunics, respectively (Cranfield et al 1999, 2001). Similar taxa have been found to play a role in biogenic reef formation and maintenance elsewhere in the world (e.g., *Modiolus modiolus* (Wildish et al. 1998), *Limaria hians* (Hall-Spencer & Moore 2000), *Pyura stolonifera* (Cohen et al. (2000)). The other characterising taxa for the Commercial strata, Balanidae and Ophiodermatidae, are respectively represented by barnacle species (e.g., *Balanus* sp.) that are directly attached to substrates such as the shells of bivalve molluscs (Foster 1978) and seastars (e.g., *Ophiosammus maculata*) that are large mobile predators of young oysters in Foveaux Strait (Stead 1971b). These characterising fauna appear to represent a biogenic reef assemblage that is modified by sustained fishing effort. The Exploratory strata assemblage was also found to be primarily characterised by the reef-forming Mytilidae and the associated Balanidae. In addition, the Calyptraeidae, a family which contains species (e.g., *Crepidula monoxyla*, *Sigapatella* sp.) that are frequently associated with oysters (Yonge 1960) was found to distinguish the Exploratory strata assemblage. These characterising taxa, are arguably consistent with a biogenic reef assemblage that is in 'regeneration' after disturbance by fishing (Cranfield et al. 1999).

Commercial and Exploratory macrofauna bycatch assemblages were, as predicted, the most similar strata in terms of taxa composition. Two taxa, the Echinometridae (sea urchin) and Bictectiporidae (bryozoa) were found to discriminate between these strata. The former family (represented by *Evichinus chloroticus*) occurred on average at more stations in the Exploratory strata, whilst the latter family (represented by *Bitectipora rostrata*) was more often found in the Commercial strata. The bryozoan *B. rostrata* was not recorded by either Fleming (1952) or Willan (1981). However, this is perhaps not unexpected for colonies of this encrusting species are not large and conspicuous (size at maturity 25–30 mm; D.P. Gordon, NIWA, pers. comm.) and could easily have been overlooked. The species is widely spread throughout New Zealand and can successfully colonise a variety of substrates (Gordon 1989); however, its response to disturbance is unknown. The sea urchin *E. chloroticus* was recorded by Fleming (1952) as "abundant in some areas", whilst Willan (1981) considered the species characteristic of nearby soft bottom habitat rather than biogenic reef itself. Nevertheless, the mainly herbivorous *E. chloroticus* is likely to be found in habitats where algae are relatively abundant. The biogenic reefs of Foveaux Strait did have greater algal cover than interspersing habitat, and *E. chloroticus* was frequently observed on seabed photographs taken of regenerating biogenic reef in 2001 (R.J. Street, pers comm.). The tests of *E. chloroticus*, like those of other echinoids, are fragile and would be readily broken by contact with fishing gear. Populations of echinoids have been found to be negatively affected in areas subjected to sustained fishing activity (Bergman & Van Santbrink 2000). Thus, it is possible to interpret the relative occurrence of the discriminating taxon *E. chloroticus* as evidence that the macrofaunal assemblages of the Exploratory strata have regenerated to a less modified state than those of the Commercial strata.

As predicted, the macrofaunal assemblage of the Background strata samples exhibited less average similarity than either the Commercial or Exploratory strata. Characterising fauna included sessile reef-forming taxa (Pyuridae, Styelidae, Mytildae), but also those typically mobile epifauna or infauna (Paguridae, Eunicidae). Pagurid hermit crabs (e.g., *Pagurus novizealandiae*) are scavengers associated with sand and gravel substrates (Forest et al., 2000), whereas the eunicid polychaetes found can occur as infauna of soft sediments (e.g., *Lumbrineris* sp.), as epifauna of coarser substrates (e.g., *Eunice* spp.) or colonise the interstices of epifaunal habitat such as biogenic reefs (*Eunice* spp., *Lumbrineris* sp.) (Rouse & Pleijel 2001). Thus, the low level of similarity between samples in the Background strata and variety of life histories of the characterising taxa support the contention that these strata encompass areas of variable seabed habitat. The level of dissimilarity observed between the macrofauna assemblage composition of the Background strata and the Commercial and Exploratory strata, is therefore understandable. Only the difference between the Background and Exploratory strata assemblages can be described by discriminating taxa. These taxa are the gastropod mollusc families Fissurellidae and Muricidae, which both occur more often in the Exploratory than in Background stations. Slit or key-hole limpets (Fissurellidae; e.g., *Monodilepas* spp.) and murex shells (Muricidae; e.g., *Xymene* spp.) were recorded by Willan (1981) and Fleming (1952) from unmodified or relatively unmodified biogenic reefs. Thus, the macrofaunal assemblage of the Background strata, whilst containing such taxa indicative of biogenic reefs, does so in proportions that would support the prediction that there is less of such habitat than in the other strata.

The results of the present survey of macrofaunal bycatch appear to support the general predictions, based on the fishers' strata designation (supported by the qualitative analysis of the fishing effort record), of the likely assemblage composition in Foveaux Strait. However, the analysis is limited to the characterisation and discrimination of three assemblages, and the spatial scale of the sampling is not directly commensurate with the scale of the fishery and the biogenic reef habitat that it is likely to affect. Thus, it is not currently possible to fully resolve the influence of fishing activity on the assemblage composition of the macrofaunal bycatch, nor state that it is sensible to use the present sampling strategy for future assessments of such fishing-induced change. Therefore, the remainder of this discussion, after briefly reviewing macrofauna bycatch surveys to date, considers some of the practical issues that influence the value of data from such surveys, and the context in which bycatch surveys contribute to fishery management.

There are few published studies of the macrofaunal bycatch of benthic commercial fisheries. Most of these studies appear to have been undertaken to detect temporal changes in bycatch composition that could be attributable to fishing disturbance, or to estimate the proportion of the catch that was discarded. In general, studies have shown that bycatch of particular taxa show temporal decreases that can be related to fishing activity (e.g., teleost fish/prawn fishery (Harris & Poiner 1990), macrofauna/beam-trawl fishery (Philippart 1998, de Vooys & van der Meer 1998)) and bycatch biomasses can be relatively high compared to those of the target fishery species (e.g., 80–90% bycatch/shrimp fishery (Evans et al. 1994, Walter 1997)). However, some bycatch studies are descriptive (e.g., Watson et al. 1990) and await further survey, or sampling design has rendered the findings somewhat ambiguous (e.g., Gray et al. 1990). In New Zealand, Probert et al. (1997) quantified macro-invertebrate bycatch abundance from trawl surveys for orange roughy (*Hoplostethus atlanticus*) near the Chatham Rise, and whilst Grove & Probert (1998) looked at macroinvertebrate bycatch biomass data from research surveys for two fisheries (hoki, *Macruronus novaezelandiae,* and orange roughy) off southern and eastern New Zealand. Both these studies detected spatial differences in bycatch composition, with the results of the former study raising concerns about impacts of the orange roughy fishery on seamount habitat and associated macrofaunal assemblages. Selective analysis of archived invertebrate bycatch samples (three taxa only) from stock assessment surveys of New Zealand's Northland scallop (*Pecten novaezelandiae*) fishery suggested a temporal decline in the number of sponge species since scallop dredging began between North Cape and Cape Reinga, although no such trend was apparent for bryozoans (Cryer et al. 2000). Cryer et al. (2002) analysed invertebrate bycatch recorded from research trawls taken as part of a study to capture and tag scampi (*Metanephrops challengeri*) in the Bay of Plenty (North Island, New Zealand). Relationships between measures of the bycatch assemblage and fishing activity were particularly evident in the early years of the fishery. Changes in species composition were thought compatible with the predicted and observed effects of other bottom contact fisheries worldwide (Cryer et al. 2002).

Despite the success of such studies in detecting and quantifying fishery impacts, bycatch studies are fraught with difficulties. Accurate assessment of bycatch, especially that of invertebrates, is not straightforward. The bulk of bycatch and the variety of species included may result in considerable effort in adequately sampling and identifying this material. Most fishery bycatch studies subsample the bycatch, and determine the biomass of a few faunal groups rather than the abundance of all species caught. Such an approach is a consequence of logistical constraints in processing large volume samples whilst at sea, and description of the bycatch usually being of secondary importance to the stock assessment of the target species. Subsampling is often the most cost-effective or feasible way to quantify the bycatch of large volume trawl catches. However, a number of factors influence how well subsamples taken from a vessel's catch sorting container represent the total catch. An assessment of how the subsampling position of the unsorted catch 'mound' affected the sample constitution found that it had no major effect on estimating the total numbers or weights of fish or invertebrates, or number of taxa (Heales et al. 2000). However, these authors noted that some taxa were sufficiently unevenly distributed in the catch that sub-sample position did influence estimates of the abundance of these individual species. Few published studies of bycatch detail how a subsample of the catch was taken. Watson et al. (1990) quantified some taxa (larger more easily identifiable organisms, e.g., sea snakes) from the whole sample, whilst other taxa (smaller, rarer organisms that were more difficult to identify) were subsampled. When recorded, post subsampling sorting and processing methodology appear to vary greatly and to the detriment of data quality (e.g., see Harris & Poiner (1990) and Walter (1997)). Gray et al. (1990) identified and enumerated all species in a series of bycatch samples. In this case, complete quantification of the bycatch was probably undertaken because samples were part of an experimental study and not an adjunct to a fishery survey. As a consequence of the quality of their data, they were able to make comparisons with assemblages that had been previously described using standard benthic sampling techniques.

The usefulness of a bycatch sample as a proxy for a standard sample of the macrofauna assemblage is habitat and gear specific. Prena et al. (1999) found that on a sandy seafloor in North America many species commonly sampled by standard epibenthic dredges and grabs were found only rarely in the bycatch of otter trawls. The bycatch of otter trawl and beam trawl on a North Sea fishing ground were very different, with the bycatch of beam trawls closely resembling the fauna sampled in the same area by standard epibenthic dredges and grabs (Philippart 1998). The commercial dredge used for collecting oysters in Foveaux Strait is operationally identical to the type of benthic research dredge most often used to sample biogenic reefs. Research dredges are generally smaller (about 1 m wide) and the catch bag made of smaller size mesh (about 20 mm) (e.g., Stead 1971a) and therefore, if towed for the same distance, retain more smaller (but less rare) organisms than commercial dredges. Even when quantification of macrofauna bycatch is a specific task of a survey and the fishing gear will effectively sample the macrofauna assemblage of the study habitat, data generated can still be of limited value. For example, Grove & Probert (1998) stressed that there were great difficulties in using some data generated by fisheries research surveys of New Zealand waters. They indicated that even inconsistently defined groupings of taxa were not handled in a standard manner, and that only the bycatch entering the processing area was recorded. The latter resulted in an underestimate of the total bycatch. Variability between individual workers and between different crews of the same vessel (intra- and inter-voyage variability) introduced further bias in the data recorded. A number of changes in bycatch recording protocol were suggested to improve the quality of such data (Grove & Probert 1998), but these suggestions have not yet been implemented in New Zealand (although it is acknowledged that MFish is planning to commission such changes in the near future).

There is a growing global emphasis on managing fisheries habitat sustainably (Moore 1999), and the New Zealand Fisheries Act 1996 incorporates a number of clauses designed to ensure the sustainable management of the habitat fished as well as that of the fish being exploited. The results of the present survey can contribute to this goal. If identification of fauna sampled to species is completed and a reference collection constructed and maintained (both preserved and digital photographic record of specimens), then data already generated will serve as a useful aid for standardising the description of diversity in future quantitative surveys in this area, thereby facilitating actions designed to ensure that the "biological diversity of the aquatic environment should be maintained" (Section 9(b) Fisheries Act 1996). However, the sampling strata in the present survey and the apparent variability in fishing activity throughout Foveaux Strait are not spatially commensurate, and therefore the sampling strategy of future surveys requires modification. That is, the sampling should be designed to elucidate any disturbance-related changes in macrofaunal assemblages at the scale of the fishery (Thrush et al. 1998). Such sampling should include monitoring, via acoustic and video techniques, of the area and distribution of the regenerating biogenic reefs, as well as describing the fauna they contain, thereby providing results which could allow "habitat of particular significance for fisheries management to be protected" (Section 9(c) Fisheries Act 1996). In addition, the distribution, abundance, and morphology of structural reef species, such as *Cinctipora elegans*, should be monitored, thereby meeting the information needs for "associated or dependent species to be maintained above a level that ensures their long-term viability" (Section 9(a) Fisheries Act 1996).

5. DIRECTIONS FOR FUTURE WORK

- To realise the full potential of macrofaunal bycatch data from the 2001 oyster stock assessment survey, all macrofauna should be identified to species level or putative species level before additional statistical analysis.

- Before further bycatch surveys are undertaken, a standard scientifically robust and logistically practicable macrofauna bycatch survey design and sampling protocol should be developed for the Foveaux Strait oyster fishery.

- Future surveys should consider specifically identifying and defining the extent of habitat of particular significance for oyster fishery management (e.g., biogenic reef).

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Table 1: Breakdown of average similarity within sampling strata into contributions from each taxon; species are ordered in decreasing contribution (cut-off applied at 90%). See text for symbol meaning.

1a. **Commercial strata** $\overline{S} = 60.55\%$

Family	A	$\overline{S}_i$	$\overline{S}_i/SD(\overline{S}_i)$	$\overline{S}_i$ %	$\Sigma\overline{S}_i$ %
Pyuridae	1.00	3.78	5.05	6.24	6.24
Ophiodermatidae	1.00	3.78	5.05	6.24	12.48
Ostreidae	1.00	3.78	5.05	6.24	18.71
Mytilidae	1.00	3.78	5.05	6.24	24.95
Balanidae	1.00	3.78	5.05	6.24	31.19
Eunicidae	0.95	3.40	2.52	5.61	36.80
Styelidae	0.95	3.31	2.59	5.47	42.27
Calyptraeidae	0.95	3.30	2.61	5.45	47.72
Glycymerididae	0.90	3.05	1.87	5.04	52.76
Paguridae	0.90	3.04	1.87	5.02	57.78
Terebratellinae	0.75	2.01	1.07	3.32	61.10
Turbinidae	0.75	1.91	1.08	3.15	64.25
Phascolosomatidae	0.70	1.66	0.93	2.74	66.99
Anomidae	0.65	1.36	0.82	2.25	69.24
Catencellidae	0.60	1.31	0.70	2.17	71.41
Didemnidae	0.60	1.28	0.72	2.12	73.53
Lichenoporidae	0.60	1.25	0.71	2.06	75.59
Pectinidae	0.60	1.19	0.71	1.96	77.55
Pinnotheridae	0.60	1.18	0.71	1.95	79.50
Bitectiporidae	0.55	1.04	0.62	1.72	81.21
Gonasteridae	0.55	1.04	0.63	1.71	82.92
Asteriidae	0.55	1.02	0.62	1.69	84.61
Hiatellidae	0.55	0.96	0.63	1.58	86.19
Muricidae	0.50	0.83	0.55	1.37	87.56
Trochidae	0.50	0.82	0.55	1.35	88.90
Fissurellidae	0.50	0.80	0.55	1.32	90.22

1b. Exploratory strata

$\overline{S} = 60.18\%$

Family	A	$\bar{S}_i$	$\bar{S}_i / SD(\bar{S}_i)$	$\bar{S}_i$ %	$\Sigma\bar{S}_i$ %
Ostreidae	1.00	3.08	4.20	5.12	5.12
Calyptraeidae	1.00	3.08	4.20	5.12	10.24
Mytilidae	1.00	3.08	4.20	5.12	15.36
Balanidae	1.00	3.08	4.20	5.12	20.49
Pyuridae	0.95	2.77	2.37	4.61	25.09
Pectinidae	0.95	2.77	2.37	4.61	29.70
Paguridae	0.95	2.74	2.38	4.55	34.25
Eunicidae	0.95	2.73	2.39	4.54	38.79
Styelidae	0.95	2.68	2.47	4.46	43.25
Ophiodermatidae	0.90	2.41	1.79	4.00	47.25
Turbinidae	0.80	1.73	1.27	2.87	50.12
Echinometridae	0.75	1.62	1.06	2.69	52.81
Trochidae	0.75	1.56	1.05	2.59	55.41
Glycymerididae	0.70	1.44	0.92	2.39	57.79
Anomidae	0.70	1.38	0.92	2.30	60.10
Gonasteridae	0.70	1.34	0.94	2.23	62.33
Pinnotheridae	0.70	1.32	0.93	2.19	64.52
Phascolosomatidae	0.70	1.31	0.93	2.17	66.69
Fissurellidae	0.70	1.27	0.94	2.10	68.80
Asteriidae	0.70	1.27	0.94	2.10	70.90
Didemnidae	0.65	1.24	0.79	2.07	72.97
Rhodosomatidae	0.65	1.11	0.82	1.85	74.81
Terebratellinae	0.65	1.07	0.82	1.78	76.60
Hiatellidae	0.60	0.99	0.71	1.65	78.25
Muricidae	0.60	0.91	0.72	1.51	79.75
Octopodidae	0.55	0.84	0.62	1.40	81.15
Horneridae	0.55	0.76	0.63	1.27	82.42
Carditidae	0.55	0.75	0.63	1.24	83.66
Dysideidae	0.50	0.70	0.55	1.16	84.82
Buccinidae	0.50	0.62	0.55	1.04	85.86
Ophiomyxidae	0.50	0.61	0.55	1.02	86.88
Lichenoporidae	0.50	0.60	0.55	1.00	87.88
Majidae	0.50	0.60	0.55	1.00	88.88
Parthenopidae	0.50	0.59	0.55	0.98	89.86
Catencellidae	0.45	0.53	0.47	0.89	90.75

1c. **Background strata** $\overline{S} = 38.08\%$

Family	A	$\bar{S}_i$	$\bar{S}_i / SD(\bar{S}_i)$	$\bar{S}_i$ %	$\Sigma\bar{S}_i$ %
Ophiodermatidae	0.90	4.23	0.48	11.10	11.10
Ostreidae	0.80	2.18	1.11	5.72	16.83
Paguridae	0.80	2.18	1.11	5.72	22.55
Pyuridae	0.75	1.71	1.06	4.50	27.05
Styelidae	0.75	1.71	1.06	4.50	31.55
Mytilidae	0.75	1.71	1.06	4.50	36.04
Eunicidae	0.75	1.71	1.06	4.50	40.54
Pectinidae	0.70	1.43	0.92	3.75	44.30
Calyptraeidae	0.70	1.43	0.92	3.75	48.05
Turbinidae	0.70	1.42	0.93	3.74	51.79
Balanidae	0.70	1.42	0.93	3.00	5.53
Pinnotheridae	0.60	1.02	0.71	2.68	58.21
Rhodosomatidae	0.60	1.02	0.71	2.67	60.89
Phascolosomatidae	0.55	0.83	0.62	2.19	63.07
Echinometridae	0.55	0.83	0.62	2.18	65.25
Hiatellidae	0.55	0.82	0.62	2.16	67.41
Carditidae	0.55	0.81	0.63	2.12	69.53
Glycymerididae	0.45	0.81	0.43	2.11	71.65
Terebratellinae	0.50	0.71	0.54	1.85	73.50
Ungulinidae	0.50	0.66	0.55	1.74	75.24
Anomidae	0.50	0.63	0.55	1.65	76.89
Didemnidae	0.45	0.62	0.47	1.63	78.53
Octopodidae	0.45	0.58	0.47	1.52	80.04
Horneridae	0.45	0.55	0.47	1.44	81.48
Asteriidae	0.45	0.53	0.48	1.39	82.87
Trochidae	0.45	0.52	0.48	1.36	84.23
Parthenopidae	0.45	0.51	0.48	1.34	85.57
Callyspongiidae	0.45	0.51	0.48	1.34	86.91
Majidae	0.45	0.48	0.48	1.25	88.16
Gonasteridae	0.40	0.44	0.41	1.17	89.33
Crellidae	0.40	0.39	0.41	1.01	90.34

Table 2: Breakdown of average dissimilarity between sampling strata into contributions from each taxon; species are ordered in dcreasing contribution (cut-off applied at 90%). See text for symbol meaning.

2a. **Commercial versus Exploratory strata** $\bar{\delta} = 41.00\%$

Family	Commercial A	Exploratory A	$\bar{\delta}_i$	$\bar{\delta}_i / SD(\bar{\delta}_i)$	$\bar{\delta}_i$ %	$\Sigma\bar{\delta}_i$ %
Echinometridae	0.25	0.75	1.06	1.22	2.59	2.59
Bitectiporidae	0.55	0.25	0.89	1.00	2.16	4.75
Catencellidae	0.60	0.45	0.88	0.97	2.14	6.89
Trochidae	0.50	0.75	0.87	0.95	2.11	9.00
Lichenoporidae	0.60	0.50	0.86	0.95	2.11	11.11
Octopodidae	0.40	0.55	0.86	0.98	2.11	13.22
Fissurellidae	0.50	0.70	0.86	0.97	2.09	15.31
Rhodosomatidae	0.50	0.65	0.86	0.96	2.09	17.40
Horneridae	0.35	0.55	0.85	0.99	2.07	19.47
Muricidae	0.50	0.60	0.85	0.96	2.07	21.54
Dysideidae	0.35	0.50	0.85	0.95	2.06	23.61
Carditidae	0.35	0.55	0.84	1.00	2.06	25.67
Hiatellidae	0.55	0.60	0.84	0.94	2.06	27.72
Asteriidae	0.55	0.70	0.83	0.92	2.03	29.76
Gonasteridae	0.55	0.70	0.83	0.92	2.02	31.78
Pinnotheridae	0.60	0.70	0.81	0.89	1.97	33.75
Majidae	0.30	0.50	0.81	0.97	1.97	35.72
Buccinidae	0.25	0.50	0.81	0.97	1.97	37.68
Didemnidae	0.60	0.65	0.81	0.89	1.96	39.65
Parthenopidae	0.30	0.50	0.80	0.97	1.96	41.61
Ophiomyxidae	0.25	0.50	0.80	0.97	1.96	43.56
Anomidae	0.65	0.70	0.78	0.85	1.91	45.47
Terebratellinae	0.75	0.65	0.78	0.82	1.89	47.37
Phascolosomatidae	0.70	0.70	0.76	0.82	1.85	49.21
Crellidae	0.20	0.45	0.75	0.91	1.83	51.04
Ophinereidae	0.40	0.30	0.75	0.89	1.83	52.87
Pectinidae	0.60	0.95	0.74	0.80	1.81	54.68
Polynoidae	0.20	0.40	0.71	0.85	1.74	56.42
Phoriospongiidae	0.20	0.40	0.71	0.84	1.73	58.15
Turritellidae	0.15	0.40	0.68	0.85	1.65	59.80
Cerioporidae	0.30	0.30	0.67	0.83	1.63	61.43
Turbinidae	0.75	0.80	0.66	0.71	1.61	63.04
Veneridae	0.05	0.40	0.66	0.81	1.61	64.65
Ungulinidae	0.25	0.30	0.64	0.79	1.57	66.22
Callyspongiidae	0.30	0.20	0.61	0.76	1.50	69.22
Glycymerididae	0.90	0.70	0.59	0.68	1.45	70.67
Temnopleuridae	0.20	0.30	0.59	0.76	1.44	72.10
Asterinidae	0.25	0.25	0.58	0.76	1.41	73.52
Lepraliellidae	0.30	0.10	0.57	0.69	1.39	74.91
Mactridae	0.20	0.20	0.53	0.66	1.30	76.21
Gobiesocidae	0.25	0.20	0.53	0.72	1.29	77.50
Arcidae	0.10	0.30	0.52	0.70	1.28	78.78
Galatheidae	0.10	0.30	0.51	0.70	1.25	80.03
Serpulidae	0.10	0.30	0.51	0.71	1.23	81.27
Portunidae	0.00	0.30	0.49	0.64	1.19	82.46
Plumulariidae	0.20	0.10	0.46	0.57	1.13	83.59
Amphiuridae	0.10	0.25	0.44	0.64	1.08	84.67
Hymenosomatidae	0.10	0.20	0.44	0.57	1.08	85.75
Haliotidae	0.10	0.20	0.41	0.58	1.01	86.76
Alpheidae	0.05	0.25	0.41	0.61	1.00	87.76

Acanthochitonidae	0.10	0.15	0.38	0.50	0.93	88.70
Aphroditae	0.05	0.20	0.37	0.53	0.90	89.60
Cinctiporidae	0.00	0.25	0.35	0.57	0.86	90.46

2b. **Commercial versus Background strata** $\bar{\delta} = 54.49\%$

Family	Commercial A	Background A	$\bar{\delta}_i$	$\bar{\delta}_i/SD(\bar{\delta}_i)$	$\bar{\delta}_i$ %	$\Sigma\bar{\delta}_i$ %
Catencellidae	0.60	0.20	1.28	0.90	2.34	2.34
Glycymerididae	0.90	0.45	1.26	0.86	2.31	4.65
Terebratellinae	0.75	0.50	1.22	0.84	2.24	6.89
Lichenoporidae	0.60	0.25	1.22	0.92	2.23	9.12
Bitectiporidae	0.55	0.15	1.16	0.90	2.12	11.24
Didemnidae	0.60	0.45	1.15	0.86	2.11	13.35
Phascolosomatidae	0.70	0.55	1.15	0.83	2.11	15.46
Anomidae	0.65	0.50	1.13	0.89	2.08	17.54
Gonasteridae	0.55	0.40	1.12	0.86	2.06	19.59
Asteriidae	0.55	0.45	1.11	0.85	2.04	21.63
Pinnotheridae	0.60	0.60	1.09	0.83	2.01	23.64
Hiatellidae	0.55	0.55	1.07	0.88	1.97	25.61
Pectinidae	0.60	0.70	1.07	0.81	1.96	27.57
Trochidae	0.50	0.45	1.06	0.87	1.95	29.52
Rhodosomatidae	0.50	0.60	1.06	0.89	1.95	31.46
Muricidae	0.50	0.10	1.05	0.86	1.93	33.39
Balanidae	1.00	0.70	1.04	0.61	1.92	35.31
Turbinidae	0.75	0.70	1.04	0.74	1.91	37.22
Fissurellidae	0.50	0.30	1.03	0.89	1.90	39.11
Calyptraeidae	0.95	0.70	1.03	0.64	1.89	41.01
Carditidae	0.35	0.55	0.99	0.93	1.83	42.83
Echinometridae	0.25	0.55	0.98	0.90	1.80	44.64
Octopodidae	0.40	0.45	0.97	0.89	1.78	46.42
Horneridae	0.35	0.45	0.97	0.85	1.77	48.19
Eunicidae	0.95	0.75	0.95	0.57	1.74	49.93
Styelidae	0.95	0.75	0.94	0.58	1.72	51.65
Pyuridae	1.00	0.75	0.93	0.55	1.71	53.36
Mytilidae	1.00	0.75	0.93	0.55	1.71	55.07
Ungulinidae	0.25	0.50	0.92	0.92	1.68	56.75
Parthenopidae	0.30	0.45	0.91	0.86	1.66	58.41
Majidae	0.30	0.45	0.89	0.86	1.63	60.04
Dysideidae	0.35	0.15	0.85	0.66	1.55	61.60
Ophinereidae	0.40	0.10	0.83	0.76	1.52	63.12
Paguridae	0.90	0.80	0.82	0.53	1.51	64.63
Lepraliellidae	0.30	0.25	0.81	0.70	1.48	66.11
Crellidae	0.20	0.40	0.80	0.78	1.47	67.58
Asterinidae	0.25	0.40	0.79	0.85	1.46	69.03
Ostreidae	1.00	0.80	0.76	0.48	1.39	70.42
Phoriospongiidae	0.20	0.30	0.75	0.64	1.37	71.79
Callyspongiidae	0.05	0.45	0.74	0.88	1.35	73.14
Arcidae	0.10	0.40	0.70	0.78	1.28	74.43
Veneridae	0.05	0.35	0.63	0.72	1.15	75.58
Cerioporidae	0.30	0.05	0.62	0.62	1.14	76.72
Apatopygidae	0.30	0.05	0.62	0.63	1.14	77.86
Mactridae	0.20	0.10	0.60	0.52	1.11	78.97
Ophiomyxidae	0.25	0.15	0.60	0.64	1.09	80.06
Serpulidae	0.10	0.30	0.59	0.67	1.09	81.15
Buccinidae	0.25	0.15	0.58	0.64	1.07	82.22
Temnopleuridae	0.20	0.20	0.58	0.64	1.06	83.28
Gobiesocidae	0.25	0.15	0.58	0.65	1.06	84.35

Polynoidae	0.20	0.20	0.57	0.65	1.04	85.39
Plumulariidae	0.20	0.00	0.52	0.42	0.95	86.34
Porcellanidae	0.00	0.35	0.52	0.73	0.95	87.29
Galatheidae	0.10	0.25	0.50	0.62	0.93	88.21
Alpheidae	0.05	0.25	0.43	0.60	0.79	89.00
Turritellidae	0.15	0.15	0.43	0.55	0.79	89.80
Aphroditae	0.05	0.25	0.43	0.60	0.79	90.59

2c. **Exploratory versus Background strata** $\bar{\delta} = 52.79$

Family	Exploratory A	Background A	$\bar{\delta}_i$	$\bar{\delta}_i/SD(\bar{\delta}_i)$	$\bar{\delta}_i$ %	$\Sigma\bar{\delta}_i$ %
Trochidae	0.75	0.45	1.09	0.87	2.06	2.06
Fissurellidae	0.70	0.30	1.07	1.05	2.04	4.10
Gonasteridae	0.70	0.40	1.05	0.95	2.00	6.10
Didemnidae	0.65	0.45	1.05	0.82	1.99	8.09
Anomidae	0.70	0.50	1.05	0.85	1.98	10.07
Glycymerididae	0.70	0.45	1.03	0.84	1.95	12.02
Echinometridae	0.75	0.55	1.02	0.81	1.94	13.96
Asteriidae	0.70	0.45	1.01	0.94	1.91	15.87
Muricidae	0.60	0.10	1.01	1.04	1.91	17.78
Phascolosomatidae	0.70	0.55	0.98	0.86	1.86	19.63
Octopodidae	0.55	0.45	0.97	0.86	1.84	21.47
Hiatellidae	0.60	0.55	0.97	0.86	1.83	23.31
Terebratellinae	0.65	0.50	0.96	0.91	1.82	25.13
Pinnotheridae	0.70	0.60	0.95	0.83	1.81	26.94
Rhodosomatidae	0.65	0.60	0.95	0.85	1.79	28.73
Dysideidae	0.50	0.15	0.94	0.87	1.78	30.50
Horneridae	0.55	0.45	0.94	0.91	1.77	32.28
Carditidae	0.55	0.55	0.93	0.91	1.76	34.03
Pectinidae	0.95	0.70	0.89	0.61	1.69	35.73
Majidae	0.50	0.45	0.89	0.92	1.68	37.41
Parthenopidae	0.50	0.45	0.89	0.92	1.68	39.10
Balanidae	1.00	0.70	0.88	0.59	1.67	40.77
Calyptraeidae	1.00	0.70	0.88	0.59	1.67	42.44
Turbinidae	0.80	0.70	0.88	0.74	1.66	44.10
Buccinidae	0.50	0.15	0.87	0.90	1.65	45.75
Lichenoporidae	0.50	0.25	0.87	0.91	1.65	47.40
Ophiomyxidae	0.50	0.15	0.86	0.91	1.63	49.03
Catencellidae	0.45	0.20	0.86	0.80	1.63	50.67
Crellidae	0.45	0.40	0.86	0.89	1.63	52.29
Ungulinidae	0.30	0.50	0.85	0.88	1.61	53.91
Veneridae	0.40	0.35	0.84	0.84	1.60	55.51
Callyspongiidae	0.40	0.45	0.84	0.91	1.58	57.09
Pyuridae	0.95	0.75	0.80	0.55	1.52	58.62
Eunicidae	0.95	0.75	0.80	0.55	1.52	60.13
Styelidae	0.95	0.75	0.79	0.56	1.50	61.64
Polynoidae	0.40	0.20	0.79	0.77	1.49	63.13
Mytilidae	1.00	0.75	0.78	0.53	1.48	64.61
Phoriospongiidae	0.40	0.30	0.77	0.85	1.47	66.08
Arcidae	0.30	0.40	0.75	0.86	1.41	67.49
Turritellidae	0.40	0.15	0.74	0.79	1.39	68.89
Asterinidae	0.25	0.40	0.72	0.85	1.37	70.26
Serpulidae	0.30	0.30	0.68	0.81	1.29	71.54
Paguridae	0.95	0.80	0.67	0.49	1.27	72.82
Galatheidae	0.30	0.25	0.64	0.78	1.20	74.02
Ostreidae	1.00	0.80	0.64	0.46	1.20	75.22

Temnopleuridae	0.30	0.20	0.62	0.72	1.18	76.41
Porcellanidae	0.20	0.35	0.62	0.80	1.17	77.57
Alpheidae	0.25	0.25	0.60	0.73	1.14	78.71
Ophinereidae	0.30	0.10	0.60	0.66	1.13	79.84
Aphroditae	0.20	0.25	0.58	0.67	1.10	80.94
Cinctiporidae	0.25	0.25	0.57	0.74	1.09	82.03
Portunidae	0.30	0.05	0.57	0.62	1.09	83.11
Bitectiporidae	0.25	0.15	0.53	0.64	1.01	84.12
Hymenosomatidae	0.20	0.15	0.53	0.55	1.01	85.13
Mactridae	0.20	0.10	0.53	0.52	1.00	86.13
Cerioporidae	0.30	0.05	0.52	0.64	0.99	87.12
Lepraliellidae	0.10	0.25	0.51	0.60	0.96	88.08
Acanthochitonidae	0.15	0.15	0.49	0.48	0.92	89.00
Ophiodermatidae	0.90	0.90	0.47	0.42	0.89	89.88
Gobiesocidae	0.20	0.15	0.44	0.61	0.83	90.71

Figure 1a: Plot of New Zealand showing the location of Foveaux Strait

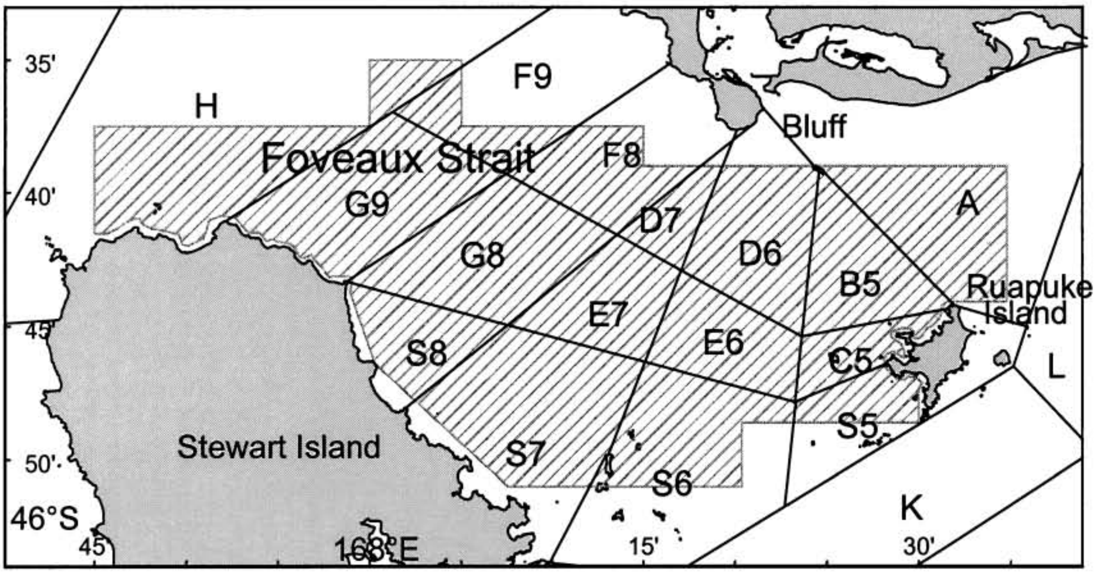

Figure 1b: Foveaux Strait (OYU 5) statistical areas, with the shaded hashed region showing the outer boundary of the October 2001 dredge survey area

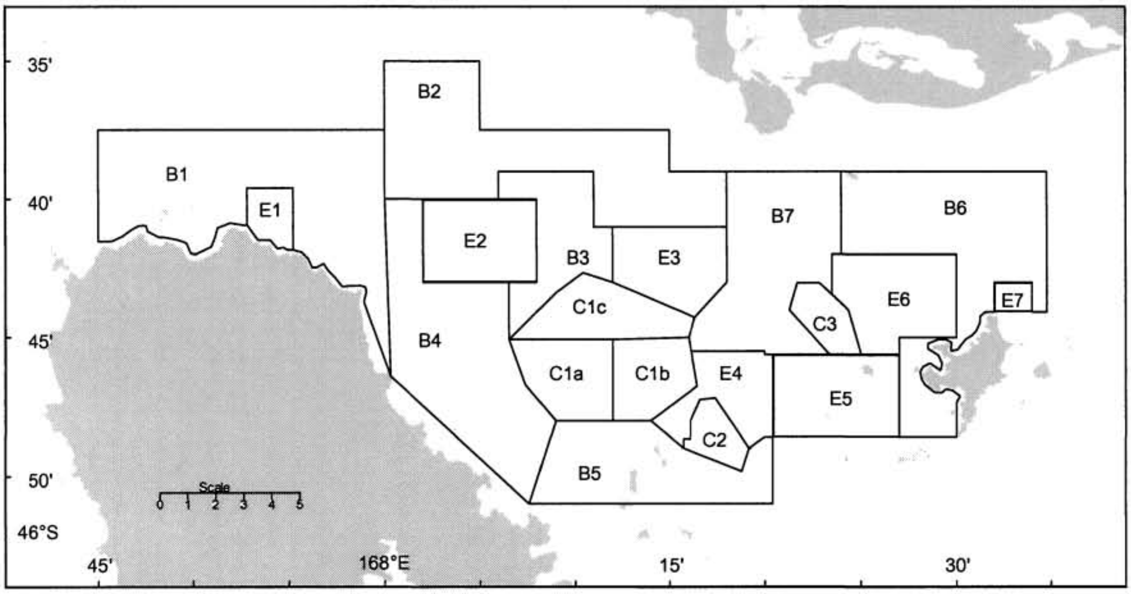

Figure 2a: Survey area in Foveaux Strait showing the Commercial (C), Exploratory (E), and Background (B) strata (and substrata) boundaries (scale bar indicates nautical miles).

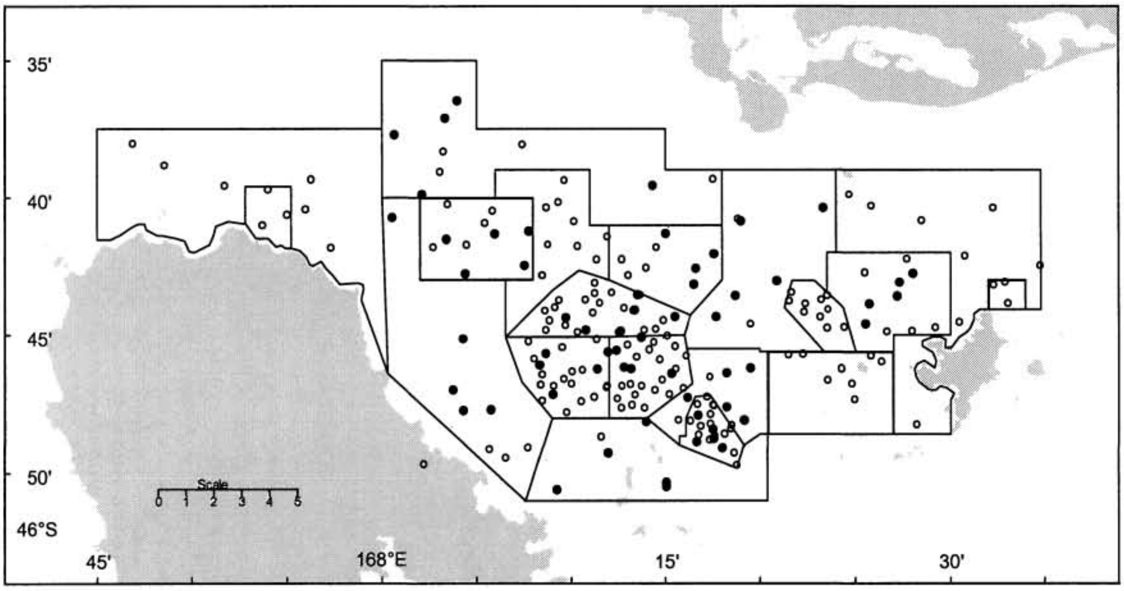

Figure 2b: Random stations used in 2001 oyster stock assessment of the survey area. Filled circles are those stations at which macrofauna bycatch was sampled (scale bar indicates nautical miles).

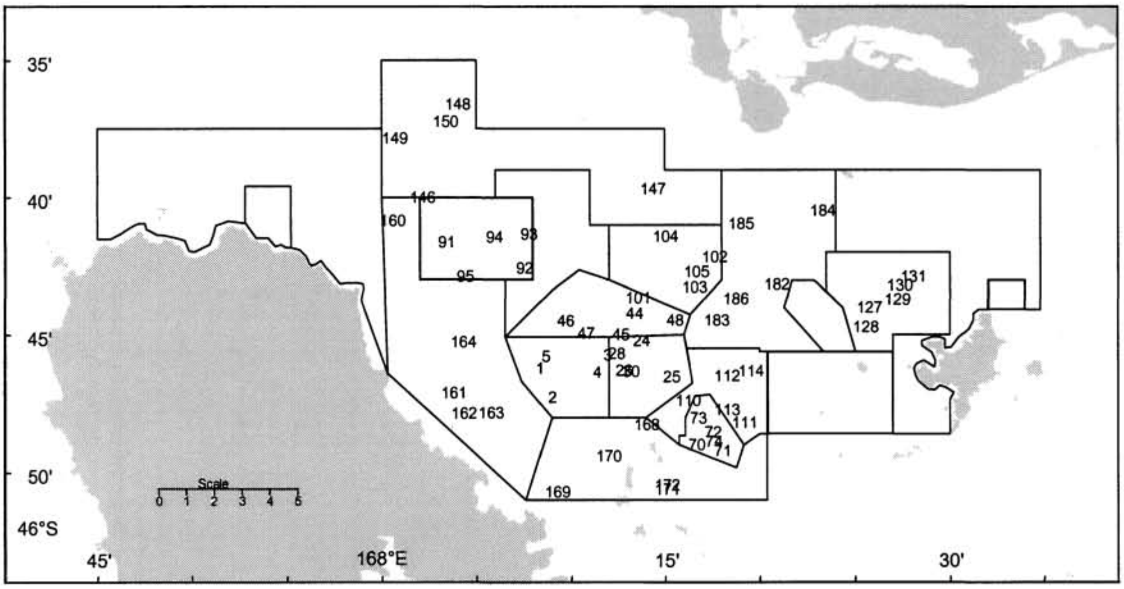

Figure 2c: Station numbers of the 60 macrofauna bycatch stations sampled in the survey area (scale bar indicates nautical miles).