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Estimates of bycatch and oyster discards from the Foveaux Strait oyster fishery (OYU 5) in February 2021 to fulfil requirements for IEMRS reporting

New Zealand Fisheries Assessment Report 2022/62

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Michael, K.P.[1] (2022). Estimates of bycatch and oyster discards from the Foveaux Strait oyster fishery (OYU 5) in February 2021 to fulfil requirements for IEMRS reporting.

***New Zealand Fisheries Assessment Report 2022/62.* 43 p.**

The Integrated Electronic Monitoring and Reporting System regulations require information on oyster catch, bycatch, and oyster discards from the Foveaux Strait oyster fishery (OYU 5) to be reported daily, at a spatial-scale of one square nautical mile based on fishers' logbook grid cells. The mode of fishing is unique to this fishery and the frequency of dredge tows does not allow for tow-by-tow reporting of bycatch and oyster discards. Fisheries New Zealand is currently exploring possible ways to substitute the bycatch data requirements with annual fishery independent surveys, representative of the fishery.

This report describes a bycatch survey undertaken in Foveaux Strait in February 2021 as part of the Fisheries New Zealand programme OYS2020-01. The bycatch survey used the design and methods agreed to by the Fisheries New Zealand Shellfish Working Group in November 2020. The survey sampled one station in each of 36 oyster fishers' logbook grid cells, stratified by four regions and three levels of fishing effort. An additional grid cell (N22) that had received virtually no fishing effort since 2006 was also sampled as a future reference grid cell. Sampling was undertaken in collaboration with the Bluff Oyster Management Company Limited who provided the survey vessel, the OYU 5 survey dredge, and crews to assist with the survey. The bycatch survey quantified oyster discards, and non-target Quota Management Species (QMS) and non-QMS species (including fish).

Fishery independent bycatch sampling was undertaken after the February 2021 oyster and *Bonamia exitiosa* (Bonamia) survey. Sampling estimated oyster discards above and below minimum legal size. Live bycatch in the dredge contents was described and quantified in the five categories required for reporting: non-fish non-QMS species, QMS commercial species, fish non-QMS, QMS reported bycatch (Porifera), and QMS reported bycatch (Bryozoa). Twelve strata were sampled in four distinctly different regions (eastern, southern, central, and western) of the commercial fishery area, each stratified by high, moderate, and low fishing effort. Three logbook grid cells were sampled in each stratum, with a single random tow in each ($n = 36$). Standard dredging methods were used, including straight-line tows landed unwashed. The dredge contents were subsampled with at least five random bins being sampled from each tow. Subsamples were scaled to tow weight and by the numbers of bins in each tow.

Commercial landings of oysters for the 2020 oyster season were 8.16 million oysters. Oyster discards above Minimum Legal Size (MLS) were approximately 8.0 million, 49.4% of all oysters caught above MLS. Discards represent 1.0% of the recruited population in the Bonamia survey area in 2021, fewer than in 2020 (1.5%). Discards of oysters below minimum legal size during the 2020 oyster season were 48.1 million oysters. The percentage of discards below MLS of the population of all sized oysters in the Bonamia survey area is 2.0% in 2021 (3.3% in 2020).

The weight of all bycatch in 2021 was 1676.2 kg, 25.0% of all the catch, representing 81 taxa, many which were rare, i.e., very few individuals of each taxon were recorded in the bycatch and the weight they contributed to the overall bycatch weight was negligible. Most (61.4%) of the bycatch was non-fish non-QMS species, which mostly (47.9%) comprised four species (in order of rank, *Astraea heliotropium*, *Modiolus areolatus, Ophiopsammus maculata*, and *Pyura pachydermatina*). The QMS reported bycatch species of the two classes of bryozoans and porifera together accounted for 33.4% of all bycatch in 2021, much higher than in 2020. Kina (*Evechinus chloroticus*) accounted for almost all QMS species (4.9% of all bycatch), sea cucumbers (*Australostichopus mollis* (SSC)*,* previously *Stichopus mollis* (STM)) accounted for less than 0.1%, and fish bycatch was negligible. Bycatch composition and volume by fishing effort needs to be viewed in the context of likely mismatches in

[1] National Institute of Water and Atmospheric Research (NIWA), New Zealand.

locations between where commercial fishing occurred and where the random bycatch sampling locations fell. Grid cells recording high and moderate fishing effort in 2020 recorded mainly mobile, ubiquitous species *A. heliotropium*, *O. maculata*, *E. chloroticus*, *Pseudechinus novaezealandie*, and *Pagurus novizealandiae*, often in very high percentages. Sessile species in these strata included *M. areolatus* and *P. pachydermatina*, also often in large percentages, and *Chondropsis* species. Grid cells recording low or no fishing effort in 2020 recorded high catches of sessile benthic fauna and usually comprised a substantial bycatch of a single species. These comprised one of *Cinctipora elegans*, *O. fusiformis*, *Crella incrustans*, and *P. pachydermatina*, and occasional moderate bycatch of *M. areolatus* and the infaunal bivalve *Glcymeris modesta* in soft, mobile gravels in the eastern fishery area. This report summarises these bycatch data by region, fishing effort, and the five bycatch reporting categories, scaled by fishing effort, to provide estimates of annual bycatch from the grid cells sampled.

1. INTRODUCTION

The Foveaux Strait oyster fishery (OYU 5, Figure 1) is a high value fishery that has been fished for over 140 years. Oysters (*Ostrea chilensis*) are an important customary (taonga), recreational, and commercial species and are important to the socioeconomics of Bluff and Invercargill. The OYU 5 stock is a Group 1 stock in the draft National Fisheries Plan for Inshore Shellfish, Ministry of Fisheries (2011). This classification recognises the relatively high biological vulnerability of Group 1 stocks (including OYU 5) and prescribes a close monitoring approach. Accurate and frequent monitoring aims to support responsive management and maximum value from Group 1 stocks. There is also an approved collaborative fisheries plan for the management of the fishery, the Foveaux Strait Oyster Fisheries Plan (Ministry of Fisheries 2009). This plan was collaboratively developed by the Foveaux Strait Oyster Fisheries Plan Management Committee, which included representatives from the Bluff Oyster Management Company (BOMC), customary and recreational fishers, and the then Ministry of Fisheries, now Fisheries New Zealand. A strategic research plan (Michael 2010) underpins the Foveaux Strait Oyster Fisheries Plan goals and objectives.

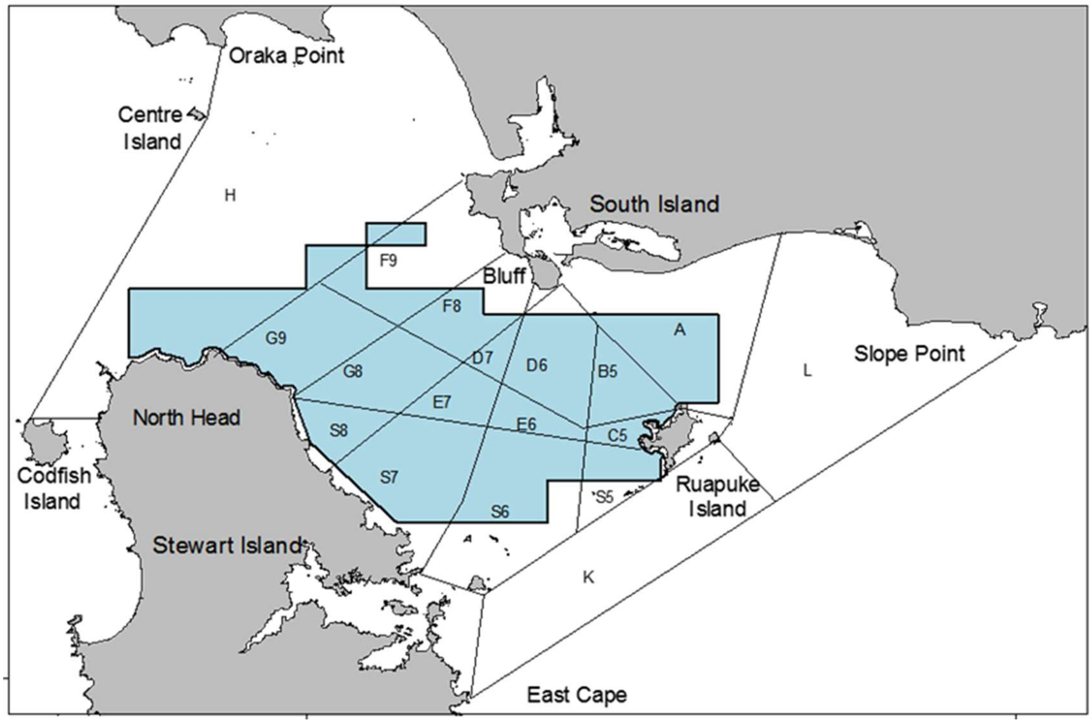

Figure 1: Foveaux Strait (OYU 5) stock boundary and oyster fishery statistical reporting areas (black text in the blue polygons), and the outer boundary of the 2007 stock assessment survey area (blue shade) encompassing almost all the commercial fishery.

The Integrated Electronic Monitoring and Reporting System (IEMRS) regulations (Fisheries New Zealand 2018) require information on oyster catch, bycatch, and oyster discards from the Foveaux Strait oyster fishery (OYU 5) to be reported daily, at a spatial scale of one nautical mile square based on fishers' logbook grid cells (Michael et al. 2012, see Figure 2). The oyster fleet had a staged transition to IEMRS reporting during the 2019 oyster season. Oyster skippers have been recording catch and effort data, oyster population size structure data, disease mortality data, and bycatch categories at this scale since 2006 and continue to concurrently record these data manually in their logbooks.

Dredging for oysters in Foveaux Strait (OYU 5) differs considerably from other commercial fishing methods that use bottom contact gears (dredges and trawls). Fishers use two dredges at a time with both deployed concurrently from the port side of the vessel in short duration, elliptical tows. This pattern of fishing maintains the vessel position over localised high-density patches of oysters ('oyster beds'). Three to four tows per hour are completed with each dredge to maintain an economic catch rate. Only commercial-sized oysters are sorted from the catch. All bycatch, including small oysters and discards of legal-sized oysters, is returned to sea within 10 minutes through a chute under the sorting bench. Sorting benches are very rarely cleared before the next tow is landed. This frequency of dredge tows and mode of fishing does not allow for tow-by-tow reporting of landings, bycatch, and oyster discards. The IEMRS reporting is at the spatial scale of logbook grid.

Fisheries New Zealand is currently exploring possible ways to substitute data requirements for IEMRS bycatch and discards reporting with annual fishery independent surveys, representative of commercial fishing.

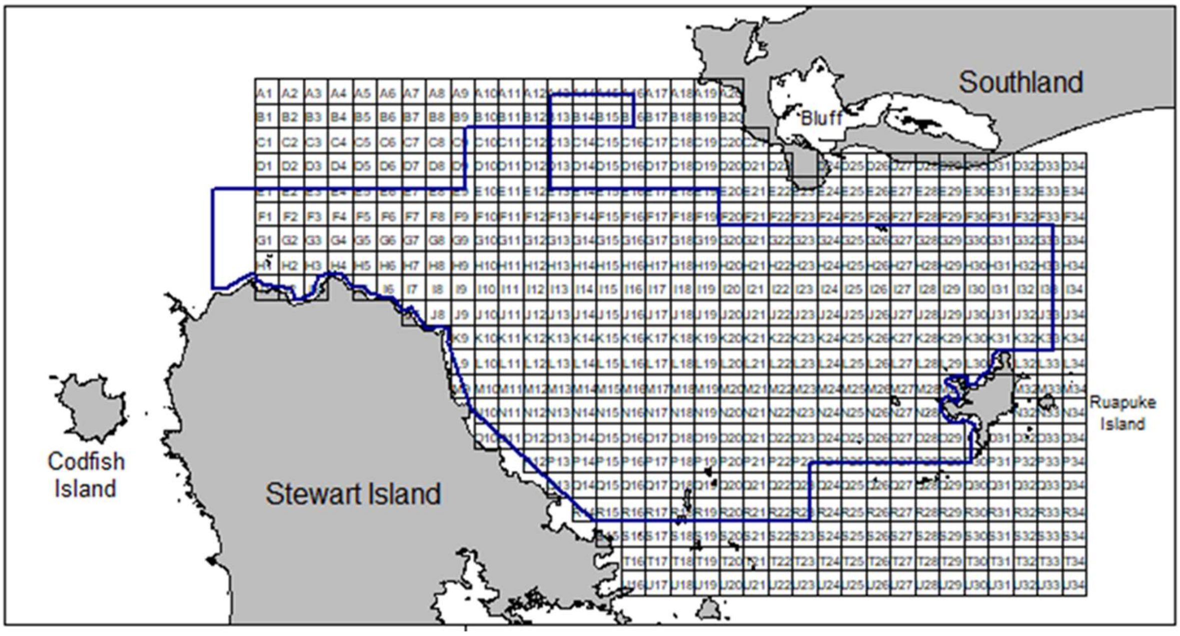

Figure 2: The Foveaux Strait oyster (OYU 5) logbook reporting grid cells (in black) and boundary for the stock assessment survey area (blue lines).

1.1 Oyster discards

Oyster size and meat condition vary spatially and temporally over the fishery area. Fishers attempt to maintain high value catch by targeting areas with high oyster meat condition and large oyster size. Meat condition and oyster size determine the spatio-temporal patterns of fishing effort and catch in the OYU 5 fishery. Recruit-sized oysters (those unable to pass through a 58 mm internal diameter ring) have a smaller maximum size in eastern fishery areas (especially areas with gravel substrates), than those from central and western fishery areas (with mostly sand substrates). Oyster meat condition is generally better in the eastern and southern fishery areas; however, meat condition varies both within oyster fishing seasons and annually. Therefore, the numbers of oysters discarded will vary across the fishery area and between years.

1.2 Bycatch

The spatio-temporal distribution of non-fish bycatch species varies (Rowden et al. 2007), dependent on whether species are mobile or sessile, with disturbance from large storms (K.P. Michael, NIWA, pers. obs.), and at a localised-spatial scale from fishing (Cranfield et al. 2004). Some species will be ubiquitous across the fishery area, while other species will have specific and localised distributions. Using presence/absence data from the 2002 Foveaux Strait oyster bycatch survey, Rowden et al. (2007) found 190 putative macrofaunal species representing 82 families and 12 phyla. Bycatch similarity measures (using pair-wise comparisons of Bray-Curtis taken at family level) indicated that the macrofaunal bycatch assemblage across commercial fishery areas were 60% similar. Bycatch families

Balanidae, Mytilidae, Ophiodermatidae, Ostreidae, Paguridae, Pyuridae, and Styelidae were found across the fishery.

Estimates of non-fish bycatch species, non-target QMS, and non-QMS species (including fish) need to be reported for IEMRS. Non-fish bycatch is reported as categorical groups (see Fisheries New Zealand 2018) that require only sponges (Porifera, coded ONG) and bryozoans (Bryozoa, coded COZ) to be reported. Macrofaunal, non-fish bycatch was expected to be diverse in this survey. Fish bycatch was expected to be negligible in this survey.

1.3 Study area

Foveaux Strait is located between the South Island and Stewart Island in southern New Zealand. The western boundary of the Foveaux Strait oyster stock area (OYU 5) is defined by a line from Oraka Point (Southland) to Centre Island and on to Codfish Island and North Head (Stewart Island) (Figure 3). The eastern boundary is a line between Slope Point (Southland) and East Cape (Stewart Island). The commercial fishery area is well defined by the 2007 stock assessment survey area (shown as blue lines in Figure 3), as all commercial fishing occurs within this area.

The western entrance to Foveaux Strait is the most exposed coastal area in New Zealand (Gorman et al. 2003), with large oceanic swells that produce a high-energy environment (Pickrill & Mitchell 1979). Mean significant wave height is 2.7 m, with waves exceeding 3 m more than 29% of the time and 10 m or more 1% of the time (Gorman et al. 2003). Tidal currents are swift and accelerate west to east (Stanton et al. 2001). This gradient in current speed is likely attributable to the decrease in depth west to east and to constrictions caused by the shoals, rocks, and islands that extend across much of the eastern entrance between Stewart Island and Slope Point.

The seafloor of the fishery area comprises gravel substrates overlaid with sand in some areas (Cullen 1962, 1967). Current flows greatly increase during storms. Storm events can mobilise sediments that scour channels and/or form sand waves, banks, and dunes (Carter & Lewis 1995, Hemer 2006). Benthic habitats vary with depth, substrate type, and wave exposure (Michael 2007) (Figure 4). High primary production (Bradford et al. 1991) supports diverse and abundant benthic communities (Michael 2010), including high densities of *Ostrea chilensis* that comprise the Foveaux Strait oyster fishery. The benthic taxa that have evolved in this high-energy environment are likely well adapted to disturbance and their recolonisation is expected to be reasonably quick (Cranfield et al. 2001).

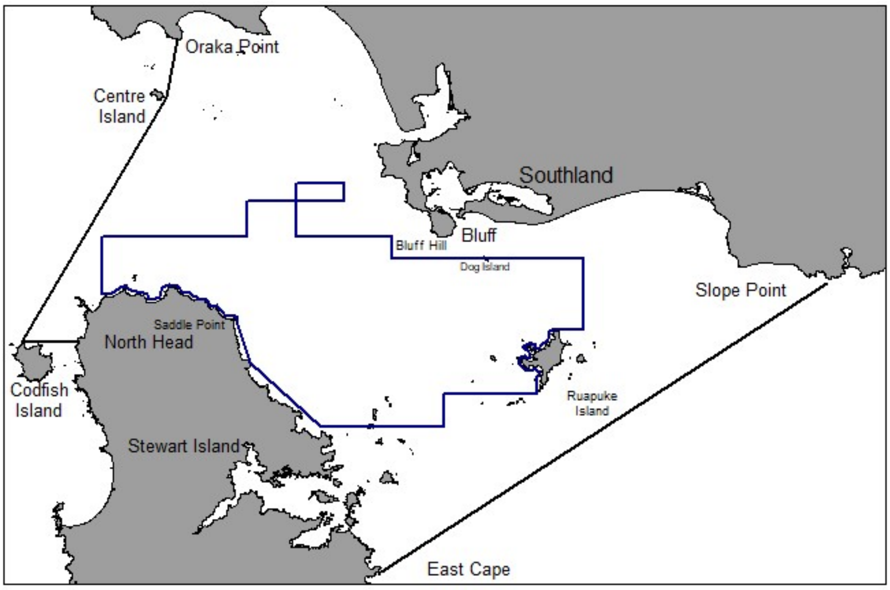

Figure 3: Foveaux Strait oyster stock (OYU 5) boundaries (black lines) and the outer boundary of the 2007 stock assessment survey area (blue line) that encompasses the commercial fishery.

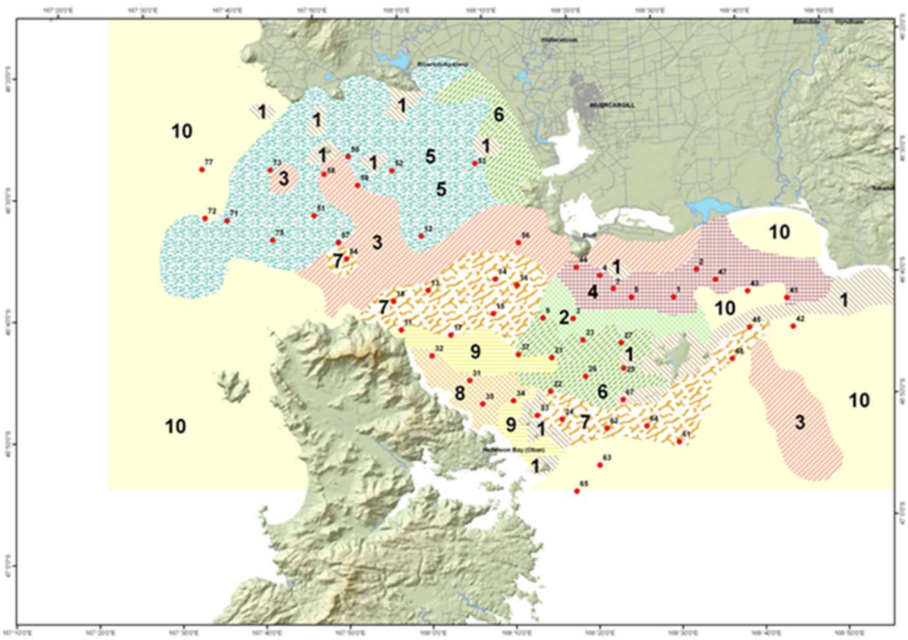

Figure 4: The distribution of subjective habitat classes based on sediment composition, structure, and stability from video transects and the sediment map of Cullen & Gibb (1966). 1, rocky patch reef with epifauna, usually surrounded by sand and fine gravels; 2, flat gravels with clean shell (usually *Ostrea chilensis*, *Oxyperas elongatum*, and *Glycymeris modesta*); 3, flat gravels and encrusted shell (usually bound by small encrusting bryozoans (Cranfield et al. 2004 and Dennis Gordon, NIWA, pers. comm.); 4, flat gravels red algae and kāeo (*Pyura pachydermatina*); 5, gravel waves or lowly undulating gravels with clean shell in the troughs; 6, flat sand and gravel; 7, flat sand and gravel with biogenic patches; 8, biogenic areas; 9, large sand waves; and 10, sand ripple.

The characteristics of the benthic habitat and substrates in each of the locations sampled within this study were described from the dredge catches.

1.4 Patterns of fishing

The patterns of fishing vary both annually and within the oyster fishing season depending on several factors. Interannual patterns are determined by the distributions of localised areas of relatively high oyster density ('oyster beds'). The oyster density in each of these oyster beds determines the catch rate and how many tows an area may receive. Because of the relatively low catch efficiency of oyster dredges (17%, Doonan & Cranfield 1992), a relatively large number of dredge tows can be made before the catch rate declines appreciably. Localised populations grow rapidly in times of good recruitment and growth, and with no or low *Bonamia exitiosa* (hereafter Bonamia) mortality. Heightened Bonamia mortality may substantially reduce oyster density below that which provides economic catch rates. For example, Bonamia mortality reduced localised oyster densities in the western fishery between 2000 and 2005, and oyster densities began to rebuild in eastern fishery areas (Michael et al. 2008). Fishing was mostly focused in eastern fishery areas in 2006 (Figure 5). However, by 2007 oyster densities in western fishery areas had begun to rebuild and fishing effort increased in the west (Figure 6).

Since 2010, fiscal incentives to land oysters with high meat condition have resulted in a disconnect between fishing (catch and effort as an estimate of relative oyster density) and oyster density estimated from fishery-independent surveys. Fishery areas with high oyster density and poor meat condition may not be fished, and areas with lower densities and high meat condition preferred. Spatio-temporal differences in oyster meat condition affect both the patterns of fishing and numbers of tows in an oyster season. Figure 7 shows highly localised and intense fishing in grid cells with high meat condition in 2015.

Other key determinants of fishing patterns include distance from port to fishing areas, weather, and tidal strengths and direction that determine steaming time and affect dredge efficiency. Daily catch limits imposed on vessels by processors affect the daily number of tows per grid cell.

Effort data are recorded at the spatial scale of grid cells; however, fishing is often concentrated in a relatively small proportion of the overall grid cell area (Figure 8). Areas of high levels of bycatch are avoided because the catch rate is much lower in these areas due to rapid dredge saturation, longer sorting times, and substantially lower catches of oysters.

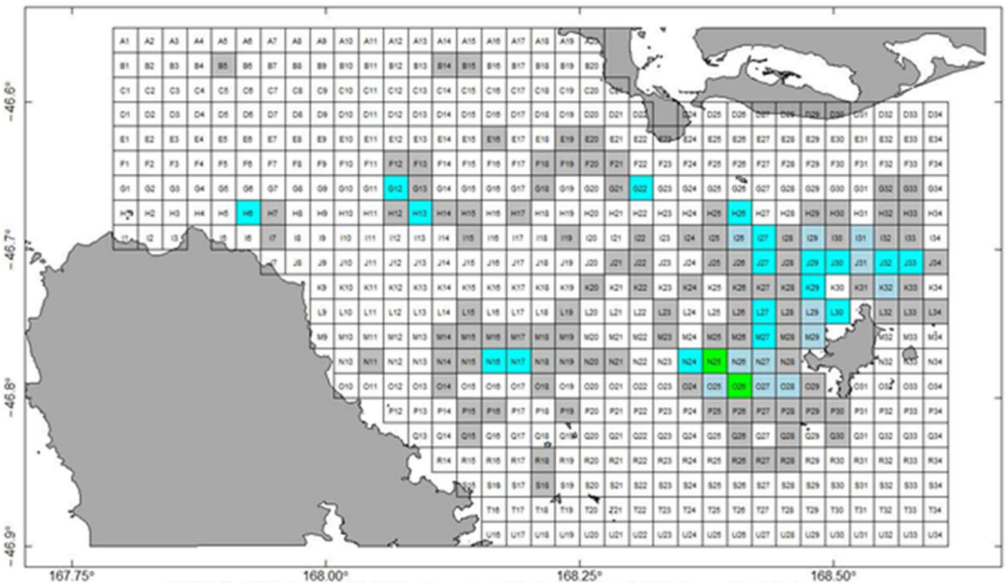

Figure 5: The distribution of dredge tows per grid cell as a percentage of total dredge tows for the 2006 oyster season, from oyster fishers' logbook data. Grid cells are shaded green ≥ 3.0% & < 5.0%, blue ≥ 2.0% & < 3.0%, cyan ≥ 0.1% & < 2.0%, and grey > 0.0% & < 0.1%. Zero tows are shown as white grid cells.

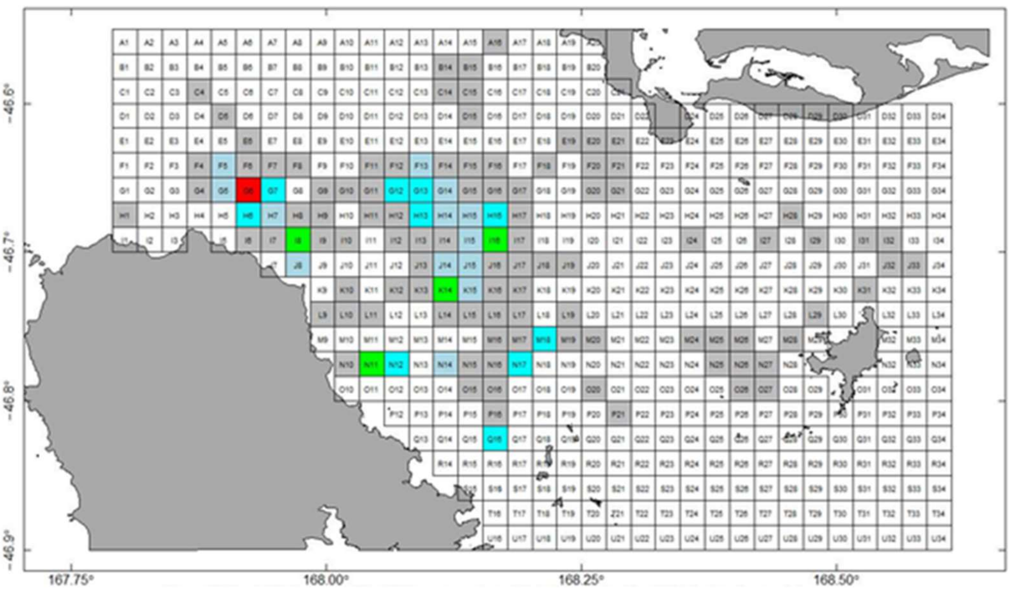

Figure 6: The distribution of dredge tows per grid cell as a percentage of total dredge tows for the 2007 oyster season, from oyster fishers' logbook data. Grid cells are shaded red ≥ 5.0% & < 10.0%, green ≥ 3.0% & < 5.0%, blue ≥ 2.0% & < 3.0%, cyan ≥ 0.1% & < 2.0%, and grey > 0.0% & < 0.1%. Zero tows are shown as white grid cells.

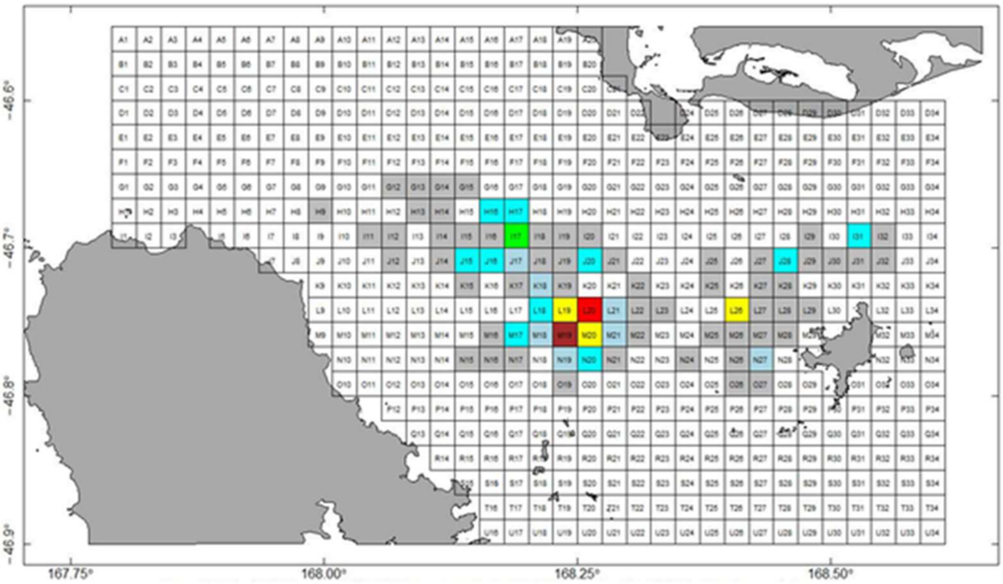

Figure 7: The distribution of dredge tows per grid cell as a percentage of total dredge tows for the 2015 oyster season, from oyster fishers' logbook data. Grid cells are shaded brown ≥ 10%, red ≥ 8.0% & < 10.0%, yellow ≥ 5.0% & < 8.0%, green ≥ 3.0% & < 5.0%, blue ≥ 2.0% & < 3.0%, cyan ≥ 0.1% & < 2.0%, and grey > 0.0% & < 0.1%. Zero tows are shown as white grid cells.

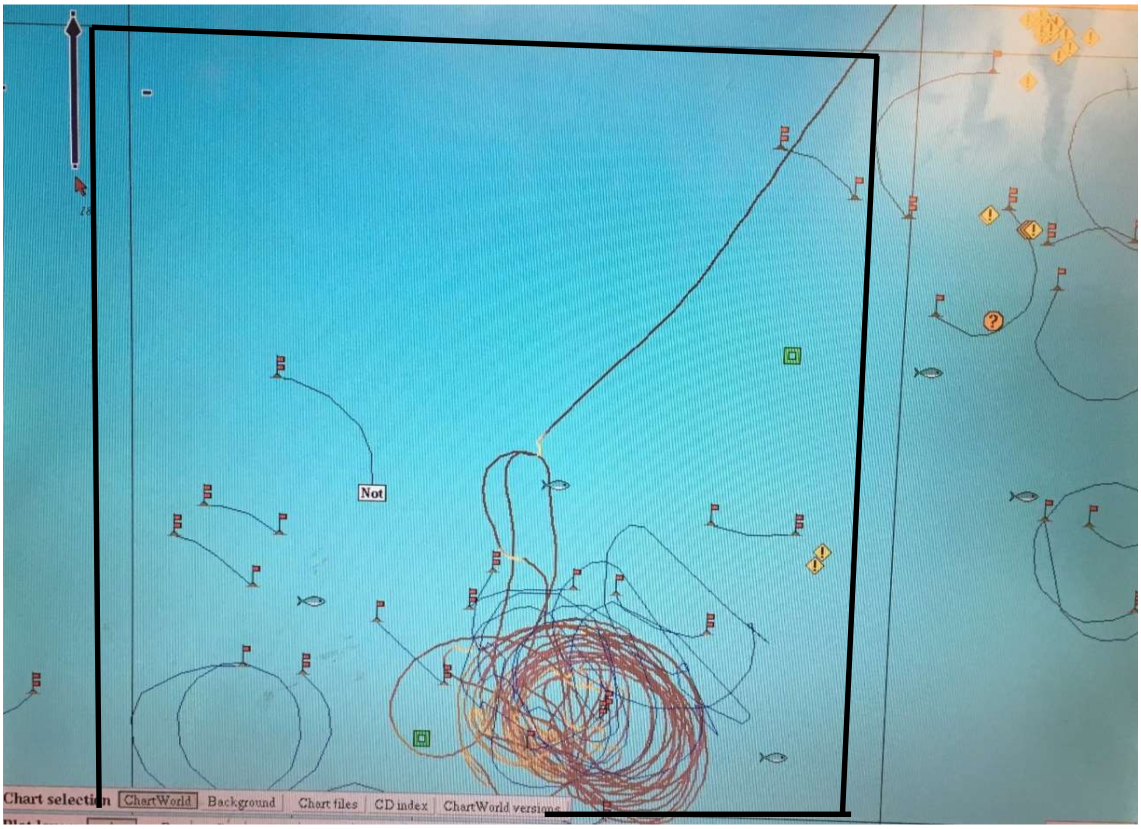

Figure 8: A screen grab of an oyster vessel's circular tracks while fishing a grid cell. Fishing is often concentrated in a relatively small proportion of the overall grid cell area. Slightly curved lines show the locations of sand banks, marked at either end with one or two flags.

1.5 Summary of results from bycatch sampling in February 2019 and February 2020

1.5.1 Pilot sampling programme in 2019

A pilot sampling programme was undertaken in conjunction with the February 2019 oyster and Bonamia surveys. Twenty stations were randomly selected from 2019 first-phase stations sampled in the Bonamia survey area representing the core fishery area where most fishing occurs (Figure 9). The Bonamia survey area represents 14 of the 26 stock assessment survey strata (46% of the area) and 69% of the recruit-sized oyster population in 2017, the last stock assessment survey. Almost all commercial fishing occurs in the Bonamia survey area. Data were collected to inform a robust sampling design to be developed and tested in 2020 (Figure 10), with the goal to estimate annual bycatch and discards from the fishery. The pilot sampling was confined to a small part of the Bonamia survey area.

The number of oysters below minimum legal size (MLS) returned to the sea and discards of oysters above MLS were likely to be significant. Oysters below MLS represented 60% of the oyster population in commercial fishery areas in 2019. Oyster discards above MLS, but below a commercial size retained by the oyster fleet and which may be returned to sea, could represent 44% of legal-sized catch.

Bycatch per tow (total catch) was low (median 29.8 kg) and much of this can be returned to sea under provision of Schedule 6. The QMS bycatch (11.2% of all bycatch) mostly comprised kina (SUR 5) and sea cucumbers (SSC 5), both on Schedule 6. Non-fish, non-QMS species were dominated by five species; the hairy mussel (*Modiolus areolatus*), 'circular saw' (*Astraea heliotropium*), brittle star (*Ophiopsammus maculata*), kāeo (*Pyura pachydermatina*), and dog cockle (*Tucetona laticostata*), which are abundant and ubiquitous throughout Foveaux Strait. It was not possible to sort live from dead colonies of *Cinctipora elegans* from the bryozoan hash; most were dead. The QMS and non-QMS fish bycatch was negligible.

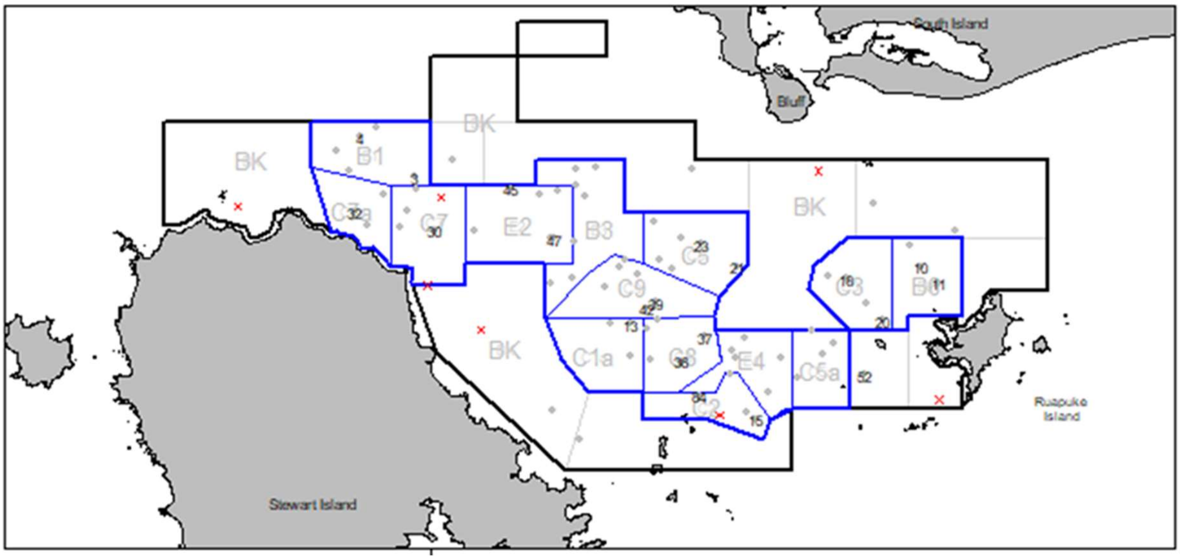

Figure 9: The 2019 survey area with the 2007 survey boundary shown as a heavy, black outer line, the Bonamia survey area as a heavy blue line, and the 2019 Bonamia survey strata shown as thin blue lines. The remaining stock assessment survey strata (light grey lines) in the large background stratum were merged into a single stratum (BK). The selection of first-phase stations sampled for bycatch during the 2019 Bonamia survey are shown in black text. Red crosses denote stations that could not be towed because of foul ground.

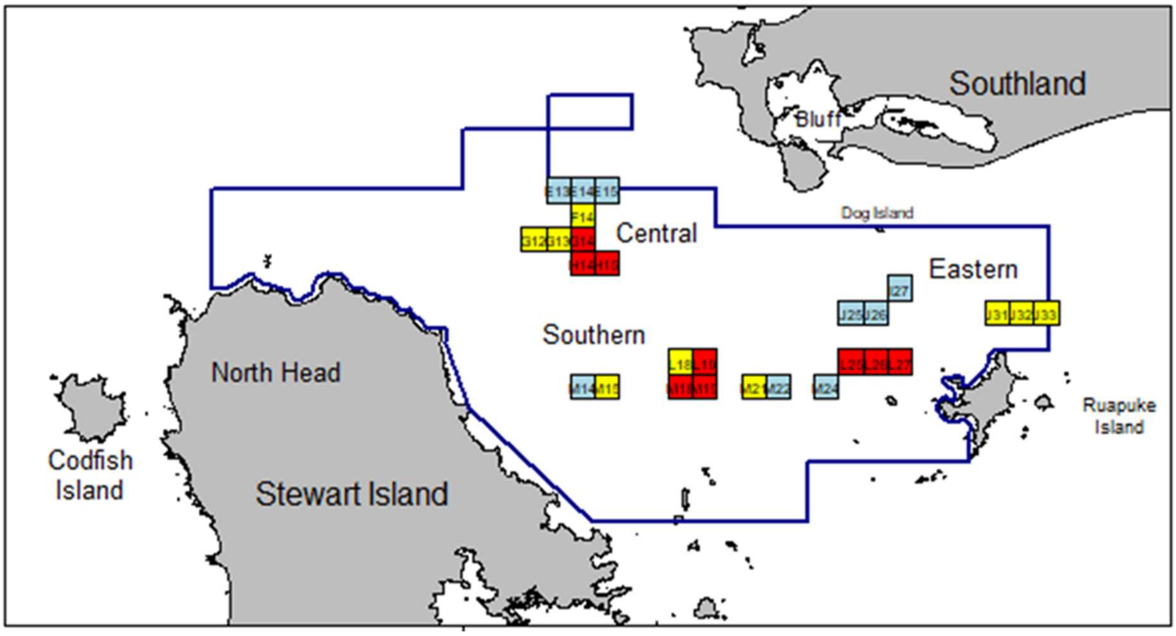

Figure 10: The location of grid cells sampled for bycatch in February 2020. The 27 tows were stratified by three regions (Eastern, Southern, and Central), three fishing effort categories (high, red; medium, yellow; and low, blue), with a single random tow in each of three replicate grid cells in each stratum.

1.5.2 Bycatch sampling in 2020

The February 2020 sampling estimated oyster discards above and below minimum legal size and described and quantified macrofaunal bycatch species (counts and weights for individual species, and weights only for colonial species) from dredge sampling. Live bycatch in the dredge contents was described and quantified in the five categories required for reporting: non-fish non-QMS species, QMS commercial species, fish non-QMS, other species (not reported as catches were negligible), QMS reported bycatch (Porifera), and QMS reported bycatch (Bryozoa). Nine strata were sampled in three distinctly different regions (eastern, southern, and central) of the commercial fishery area, each stratified by high, moderate, and low fishing effort. Three logbook grid cells were sampled in each stratum, with a single random tow in each (n = 27) (see Figure 10). Standard oyster survey dredging methods were used (including straight-line tows landed unwashed, see Michael et al. 2021). Survey tows were used instead of the washed, elliptical tows used by commercial vessels, to allow the area swept and densities to be estimated. The dredge contents were subsampled with at least five random bins being sampled from each tow. Each taxon in subsamples was scaled to their total weight in the catch by the proportion of bins subsampled to the total number of bins.

Bycatch sampling was undertaken in February 2020, between the 2019 and 2020 oyster seasons. Mean weight of catch per tow (including shells of dead bivalves and gravel) over all 27 tows was 470 kg (including oysters) of which a mean of 18 kg (4%) was live bycatch. Bycatch generally accounted for a small percentage of the dredge contents by weight.

Median scaled bycatch weight of all bycatch species, across all tows was 3.0 kg per tow. Of the weight of all bycatch combined, 83.2% was non-fish non-QMS species. Four species accounted for 60.1% of bycatch: *Astraea heliotropium*, *Ophiopsammus maculata*, *Pyura pachydermatina*, and *Modiolus areolatus* by weight. At stations where bycatch weight was high, these tows mostly comprised catches of *P. pachydermatina* and *M. areolatus*. Kina (*Evechinus chloroticus*) dominated catches of QMS species, comprising 6.8% of all bycatch. Catches of QMS fish species, QMSR_ONG (Sponges), and QMSR_COZ (Bryozoa) were low, regardless of region and fishing effort.

Bycatch weight differed by region and by fishing effort. The median weights of bycatch were higher in grid cells with high fishing effort and lowest in grid cells with low fishing effort. There were some differences in the composition of bycatch within region, which may reflect differences in benthic habitats and benthic communities rather than fishing effort per se (Michael 2022). Moreover, patterns of fishing may be driven by the distributions of bycatch and bycatch volumes. Most bycatch is returned within 10 minutes; however, little is known about the incidental mortality of bycatch species.

1.5.2 Oyster discards in 2020

Oyster discards above minimum legal size during the 2019 oyster season were 44.7% (7.8 million oysters), representing approximately 15% of the recruited oyster population in the Bonamia survey area. Discards of oysters below minimum legal size during the 2019 oyster season were approximately 61.0 million oysters, or 3.3% of the total estimated oyster population in February 2020 in the Bonamia survey area.

2. OBJECTIVES

Overall OYS2020-01 Research Programme Objectives:

1. To evaluate the current abundance and biomass of oysters in the OYU 5 fishery and to evaluate current and expected oyster mortality from Bonamia infection for the fishing years 2020, 2021, and 2022.
2. To evaluate the current status of the prevalence and intensity of Bonamia in the OYU 5 fishery for the fishing years 2020, 2021, and 2022.
3. To conduct a bycatch survey that will provide estimates of current bycatch levels where the fishery occurs for the fishing years 2020, 2021, and 2022.

This report summarises bycatch sampled in February 2021, completing Objective 3. This bycatch sampling used the same methods as for the February 2020 sampling programme.

Specific bycatch and discard sampling Objectives:

1. Conduct a bycatch survey to provide estimates of bycatch levels of the fishery for the 2020–21 and 2021–22 fishing years.

Specifically, undertake fishery independent bycatch sampling with an aim:

a. To estimate oyster discards above and below minimum legal size, and
b. To describe and quantify bycatch in the five categories required for IEMRS reporting: non-fish non-QMS species, QMS commercial species, fish non-QMS, QMS reported bycatch (Porifera), and QMS reported bycatch (Bryozoa).

3. METHODS

The framework for February 2021 bycatch sampling was developed in collaboration with the Shellfish Working Group and Fisheries New Zealand (Marine Pomarède and Marco Milardi). The Fisheries New Zealand Shellfish Working Group in 2020 recommended that a fourth, western fishery area be sampled in 2021, to ensure sampling of all commercial fishery areas, and that the design and sampling methods should remain the same as in 2020. The Shellfish Working Group also recommended that one grid cell that is not regularly fished is sampled every year to maintain a time series from that grid cell. The February 2021 bycatch survey estimated oyster discards and bycatch in the areas fished during the 2020 oyster season. These surveys were undertaken in collaboration with the Bluff Oyster Management Company who provided the survey vessel, a standard survey dredge, and crews for the survey.

The February 2021 bycatch survey sampled 12 strata in four distinctly different regions (western, eastern, southern, and central) of the commercial fishery area, each stratified by high, moderate, and low fishing effort (annual numbers of dredge tows per logbook grid cells). Three grid cells were sampled in each stratum (region and fishing effort), with a single random tow in each. Grid cells within each stratum were chosen as close as possible to each other to maintain, as much as possible, homogeneous habitats, bycatch assemblages, and oyster densities as well as fishing effort. Because low effort grid cells are relatively rare, no effort grid cells are occasionally chosen to ensure, as much as possible, similar habitats are being sampled as replicates. Where possible, three-alphabetic species codes were used, or the lowest taxonomic level recorded. Species codes and corresponding species names are given in Table A1.1 (Appendix 1).

3.1 Delineation of regions

The commercial fishery area of OYU 5 was divided into four regions based on data summaries of Catch Effort Landing Return (CELR) reporting by the statistical areas (1960–1990), survey strata, and fishers' logbook data from the 2020 oyster season. The four regions represent core fishery areas identified from CELR data: in the west (G8, Saddle bed), central (E7), southern (S7), and eastern (A, B5, and C5), see Figure A2.1 (Appendix 2). These four partitions of the fishery are broadly consistent with the Bonamia survey area representing the core commercial fishery area and the Bonamia survey strata (Figure A2.2, Appendix 2). When the 2020 fishers' logbook data are overlaid on these four regions, western and eastern areas are well delimited, and central and southern are contiguous (Figure A2.3, Appendix 2).

3.2 Selection of grid cells

Cells with high, medium, and low or no fishing effort were identified from the 2020 oyster season fishers' logbook data, which accounts for 100% of fishing effort. Four regions representative of the distribution of commercial fishing in the western, central, southern, and eastern fishery areas were selected. The habitats and benthic assemblages differ over the fishery area.

Because of the cyclical nature of oyster abundance caused by disease (*Bonamia exitiosa*) mortality, the percentage of annual catch from each grid cell cannot be used as a proxy for fishing effort as the relationship between the numbers of dredge tows per grid cell per day and the numbers of sacks of oysters is not linear (Figure A3.1, Appendix 3).

The number of dredge tows per grid cell is used as a measure of relative fishing intensity (hereafter effort), where each deployment equals two dredge tows. The number of annual dredge tows per grid cell (where fishing occurred) was combined for all vessels. Grid cells with high fishing effort are defined as those close to the 95th percentile of the number of tows per grid cell in a region; moderate fishing effort as close to the 50th percentile; and low fishing effort as below the 5th percentile. A summary of the total number of dredge tows in each stratum is given in Table 1. During the 2020 oyster season, 27 053 tows were recorded in the fishery area, and all regions received some fishing. The western region accounted for most of the catch (38.5%) and most of the tows (37.5%) in 2020, with 36.4% of these tows in the three high effort grid cells (I17, G15, and H15). In decreasing order of effort, the central region received 27.4% of all effort and 28.0% of the catch, the southern region 19.5% of effort and 20.8% of catch, and the eastern region was lowest with 15.6% of effort and 12.7% of catch (Figure 11 and Table 1).

The number of tows in the high fishing effort strata varied both between regions and within region, especially the eastern region. This variation is most likely driven by differences in catch rate and meat quality. After the selection of grid cells from the 2020 fishers' logbook data, grid cell N22 (see Figure 11) was selected to be sampled every bycatch sampling year to provide a reference cell for future monitoring of an unfished area. Between 2006 and 2020, only two prospecting tows have been reported in grid cell N22—in 2014. Grid cell N22 is close to an area that has been constantly fished since 2006 (Figure 11).

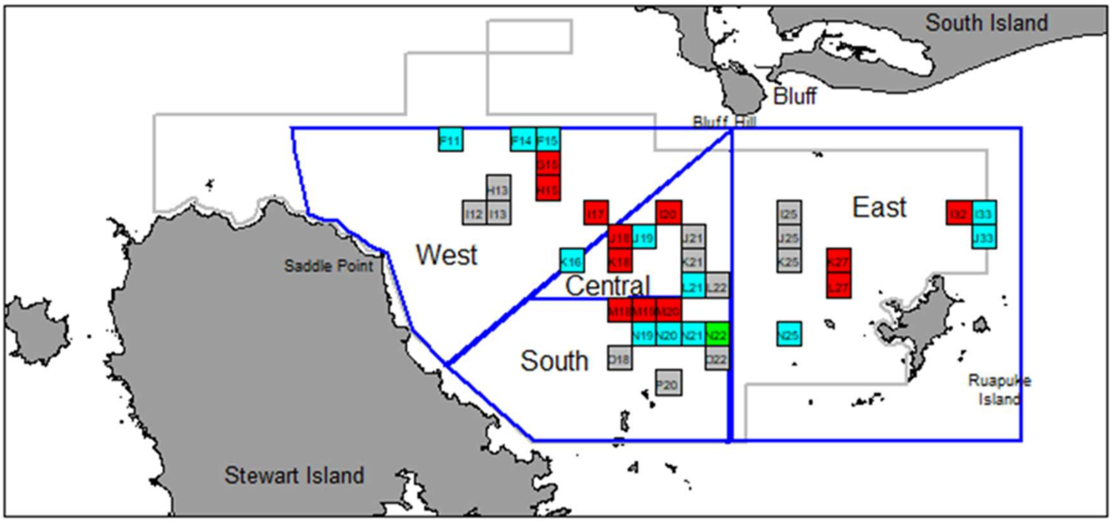

Figure 11: The four fishery regions (West, Central, South, and East) shown as blue lines, the stock assessment survey area shown as grey lines and selected fishers' logbook grid cells that represent high (red), moderate (cyan), and low (grey) fishing effort. Grid cell N22 selected as an unfished cell to be regularly sampled is shaded green.

Table 1: A summary of effort and percentage annual catch from the 2020 Foveaux Strait oyster season (1 March to 31 August). The data are presented for the selection of one nautical mile square grid cells (Grid) to be sampled during the 2021 bycatch survey by region and effort category, and for all grid cells fished in each region in 2020. Total number of dredge tows for all vessels combined (Tows), the total number of vessel days fished (Vessel days), and the percentage of the annual catch from the entire fishery (% Catch).

Region	Effort	Grid	Tows	Vessel days	% Catch
Central	High	J18	1 844	51	7.7
Central	High	L20	1 720	41	7.3
Central	High	K18	1 027	26	3.3
Central	Moderate	L21	108	6	0.4
Central	Moderate	J19	86	5	0.5
Central	Moderate	K16	72	1	0.2
Central	Low	J21	2	1	0
Central	Low	L22	2	1	0
Central	Low	K21	0	0	0
Central	-	All grid cells	7 413	204	28
Region	Effort	Grid	Tows	Vessel days	% Catch
East	High	L27	1 420	32	4.8
East	High	K27	434	10	1.3
East	High	I32	402	11	0.9
East	Moderate	N25	44	2	0.1
East	Moderate	J33	40	2	0.1
East	Moderate	I33	32	1	0.1
East	Low	I25	2	1	0
East	Low	K25	2	1	0
East	Low	J25	0	0	0
East	-	All grid cells	4 228	135	12.7
Region	Effort	Grid	Tows	Vessel days	% Catch
South	High	M19	1 445	44	6.6
South	High	M18	1 133	30	3.8
South	High	M20	957	28	4.5
South	Moderate	N19	156	4	0.7
South	Moderate	N20	72	2	0.3
South	Moderate	N21	69	4	0.2
South	Low	O18	1	1	0
South	Low	O22	1	1	0
South	Low	P20	1	1	0
South	-	All grid cells	5 262	159	20.8
Region	Effort	Grid	Tows	Vessel days	% Catch
West	High	I17	1 510	35	6.8
West	High	G15	1 040	27	4
West	High	H15	846	25	3.2
West	Moderate	F15	79	4	0.5
West	Moderate	F11	67	3	0.4
West	Moderate	F14	41	2	0.1
West	Low	I12	10	1	0.2
West	Low	H13	4	1	0.1
West	Low	I13	0	0	0
West	-	All grid cells	10 150	306	38.5

3.3 Sampling methods

A single tow was made in each of the 36 grid cells selected (three grid cells each in the four regions for each of the three effort categories) (Table 1, Figure 11), and an additional tow made in grid cell N22. Tow start positions were allocated using random numbers to determine *xy* coordinates within grid cells. Tows followed standard OYU 5 dredge sampling methods (Michael et al. 2021), i.e., straight-line, 0.2 nautical mile survey tows to allow area swept to be calculated and thereby bycatch to be quantified. Commercial fishers use elliptical tows. The dredges were landed unwashed rather than washed to better describe bycatch taxa present in the dredge and on the seabed.

3.3.1 Estimates of oyster discards

Oyster discards were estimated in two size categories, below minimum legal size (MLS) and above MLS. *Nda* is the number of oysters discarded above MLS and *Ndb* below MLS. *Nda* is calculated from the dredged recruit-sized catch (Cc), which is the total number of oysters above MLS (recruit-sized) landed on the vessel before sorting of the catch and discards.

The number of oysters caught (Cc, millions) by all vessels in 2020:

$$Cc = \frac{L}{PL}$$

Where:
L is the Fisheries New Zealand reported commercial landings of oysters for the 2020 oyster season
PL is the proportion of oysters retained and landed as commercial catch, calculated from survey estimates of population size and from bycatch sampling in February 2021:

$$PL = 1 - \frac{(all\ recruit - sized\ +\ Commercial\ size)\ -\ Commercial\ size}{all\ recruit - sized\ +\ Commercial\ size}$$

Oyster discards were estimated from two data sources to give the likely range of discards for oysters above and below MLS: (1) the population size of oysters in each of the four size categories from the February 2021 oyster survey and (2) counts of live oysters in each of the four size groups from dredge tows sampled during the February 2021 bycatch survey. The percentage of discards below MLS were estimated as the number of pre-recruit and small oysters over the total number of oysters, comprised four size groups: 'commercial' oysters (unable to pass through a 65 mm internal diameter ring (IDR)); recruit-sized (able to pass through a 65 mm IDR, but unable to pass through a 58 mm IDR); pre-recruits (able to pass through a 58 mm IDR, but unable to pass through a 50 mm IDR); and small oysters (able to pass through a 50 mm IDR and down to 10 mm in length). The percentage of discards above MLS were estimated from the number of oysters above MLS (recruit and commercial-sized oysters combined) but below commercial size.

Oyster discards above MLS

Nda, the number of oysters discarded above minimum legal size (MLS), are the recruit-sized oysters (≥ 58 mm in diameter) that are sorted from the catch and returned to sea. Estimates of *Nda* assume that all oysters above commercial size (≥ 65 mm diameter) are retained and landed, and all oysters above MLS but below commercial size (i.e., 58─64 mm in diameter) are returned to sea.

The number of oysters (millions) above MLS discarded during the 2020 oyster season, *Nda*, is calculated by:

$$Nda = Cc - L$$

Oyster discards below MLS

The number of oysters discarded below MLS (*Ndb*) are the oysters < 58 mm diameter, returned to sea.

The number of oysters discarded (*Ndb*) is calculated by scaling dredged recruit-sized catch (*Cc*) by the proportion of oysters below MLS (*Pdb*) from population estimates and bycatch sampling.

The number of oysters (millions) below MLS discarded by all vessels in 2020 (*Ndb*):

$$Ndb = \frac{Cc}{1-Pdb},$$

where *Pdb* is given by:

$$Pdb = \frac{all\ oysters\ below\ MLS\ (pre-recrui\ \ and\ \ small-sized)}{all\ oysters\ (all\ sizes)}.$$

Pdb1 is from the survey estimates of population sizes in February 2021.
Pdb2 is the mean proportion of oysters below MLS that were below MLS from bycatch sampling.

3.4 Estimates of fish and non-fish, QMS, and non-QMS bycatch

Bycatch data were summarised to quantify catches of QMS and non-QMS species (other than oysters). All the catch (dredge contents) from each tow were landed into bins and numbers of bins were recorded. Five or more bins were randomly subsampled and weighed to a lower limit of 0.1 kg. Each bin was treated as a replicate and sorted separately. All live oysters were sorted to four size groups (see above), and all bycatch were sorted to species (or lowest taxonomic group possible) and weighed, and non-colonial taxa were counted. To maintain sampling efficiency, individual taxa were weighed to a minimum weight of 0.1 kg; however, many samples of taxa were much lighter than 0.1 kg. For each species in each tow, scaled weights were calculated by combining all subsampled weights for the species and scaling to the total catch (total bins / subsampled bins). All summaries are presented as scaled weights (in kilograms).

All bycatch data were partitioned and coded into five categories given below. Table 2 gives the required non-fish bycatch reporting (see Fisheries New Zealand 2018):

- NFNQMS, non-fish, non-QMS species,
- QMS, QMS commercial species,
- NQMSF, fish, non-QMS
- QMSR_ONG, QMS reported bycatch (Porifera),
- QMSR_COZ, QMS reported bycatch (Bryozoa).

Table 2: Non-fish bycatch reporting.

Common name	Scientific name	Code
Corals, sponges, and bryozoans	Porifera (Phylum), Bryozoa (Phylum), Alcyonacea (Order), Gorgonacea (Order), Scleractinia (Order), Antipatharia (Order), Stylasteridae (Family)	CSB
Coral (unidentified)	Alcyonacea (Order), Gorgonacea (Order), Scleractinia (Order), Antipatharia (Order), Stylasteridae (Family)	COU
Sponges	Porifera (Phylum)	ONG
Bryozoan	Bryozoa (Phylum)	COZ

3.5 Estimates of bycatch scaled to fishing effort for the 2020 oyster season

Estimates of bycatch for the 2020 oyster season by region (western, central, southern, and eastern) and by fishing effort strata (high, moderate, and low) are calculated from the mean (Bycatch 1) and median (Bycatch 2) weight of all bycatch species in the February 2021 survey combined, scaled by the mean number of tows recorded from each stratum (region and fishing effort, n = 3 grid cells each stratum), from fishers' logbooks in 2020. Bounds for percentage bycatch (calculated from median weight) are given as 5th and 95th percentiles. The bycatch weight for each stratum in each region as a percentage of the total bycatch weight from all 36 grid cells combined is calculated using median weights. Medians are used to reduce the effects of occasionally large catches. The size of the annual catch is primarily driven by the scaling factor (i.e., the annual number of tows per grid cell); however, the bycatch remaining on the seabed is expected to decline quickly with increasing fishing effort, and the relationship between number of tows and total bycatch to be non-linear.

4. RESULTS

4.1 Summary of sampling in 2021

The February 2021 survey sampled an extra region (western) not sampled in the February 2020 survey, and an additional grid cell (N22). As for the 2020 bycatch survey, grid cells were sampled with a single, random tow in 2021. Summaries of combined catch were therefore not directly comparable between 2020 and 2021 (27 grid cells compared with 37 grid cells, respectively).

Of the 547 bins (23 887 kg) total catch from 37 tows sampled in February 2021, 177 bins (32.4%, including oysters) of the dredge contents were subsampled. The total numbers of bins per tow ranged from 0.5 to 32.0 in 2021, with a mean number of bins per tow of 6.9. The net weight of individual, subsampled bins ranged from 2.0 to 68.4 kg in 2021. Mean bin weight, including oysters, was 38.8 kg. Bycatch generally accounted for a small percentage of the catch weight. Most of the catch comprised the shells of dead bivalves, gravel, and dead bryozoan hash.

4.2 Non-oyster Bycatch

All bycatch summaries excluded data on live oysters. Only four of the five bycatch categories are reported below. Fish, non-QMS other species, are not reported as catches were negligible.

4.2.1 Bycatch for all regions combined

The weight of each species in each category is given in Table A3.1 (Appendix 3). The combined, scaled weight of bycatch was 1676.2 kg, 25.0% of the total unsorted catch. Bycatch by category is given in Table 3 and the ten highest ranked bycatch species by total weight across the four regions combined are given in Table 4. Non-fish non-QMS species (NFNQMS) accounted for 61.4% of bycatch (Table 3), of which 47.9%) comprised four species, in order of rank, *Astraea heliotropium*, *Modiolus areolatus, Ophiopsammus maculata*, and *Pyura pachydermatina*. Three of these species, the large gastropod, *A. heliotropium* (ASH, 20.1%), the mussel *M. areolatus* (MAR, 12.5%), and the brittle star *O. maculata* (OMA, 9.5%) are ubiquitous throughout the Foveaux Strait fishery area, and their combined weight accounted for 42.1% of all bycatch (Table 4). The stalked ascidian or 'sea tulip, kāeo' (*P. pachydermatina*) is mostly confined to southern and eastern fishery areas where it forms dense stands. *Pyura. pachydermatina* accounted for 5.8% of all bycatch (all regions combined). At the site with the highest catch, station 6 (eastern region, moderate effort) sample bins weighed 12–21 kg.

Bycatch of the two categories bryozoans (QMSR_COZ) and porifera (QMSR_ONG) combined accounted for a further 33.4% of all bycatch in 2021, which was much higher than in 2020 (4.4%). For details on species within each category, see Table A3.1 (Appendix 3). Bycatch of the branching bryozoan, *Cinctipora elegans* (CEL), comprised live colonies and dead hash. Live CEL colonies were inseparable from the dead, and the total weight of live and dead CEL accounted for 23% of all bycatch from a single station: station 34 (Southern region, low effort), subsampled bins contained approximately 40 kg of live and dead CEL.

Bycatch of QMS species was small. Kina *Evechinus chloroticus* (SUR) accounted for 4.9% of all bycatch (all regions combined) (Table 4) and was mostly confined to the eastern fishery area. Other QMS species, including sea cucumbers (*Australostichopus mollis*, SSC) accounted for less than 0.1% of the bycatch. QMS fish bycatch was negligible.

Median bycatch of all species (excluding oysters) across all tows ($n = 37$), was 26.2 kg (5^{th} to 95^{th} percentiles, 1.2–116.8 kg). The weights of bycatch per tow in 2021 were generally similar to 2020, except for the large catches of CEL. Mean weight of individual species was less than 3.0 kg per tow, except for CEL. Weight per tow by bycatch category is shown in Figure 12. Bycatch was highest and most variable for non-fish, non-QMS other species, especially the large epibenthic taxa. Highly variable catches of *C. elegans*, *P. pachydermatina,* and *M. areolatus* suggest that the distribution of these species was patchy, and their densities were variable.

The box plots of catches by bycatch category and fishing effort (Figure 12) show bycatch of NFNQMS was relatively high, regardless of fishing effort. Catches of QMS species and sponges (QMSR_ONG) were relatively low (Table A3.1 of Appendix 3), also regardless of fishing effort. Isolated, large catches of bryozoans QMSR_COZ were from grid cells with the lowest fishing effort (Figure 12).

Table 3: Total weight (kg) of bycatch from all grid cells (n = 37) and percentage of bycatch weight by category: NFNQMS (non-fish, non-QMS, other species not reported), QMS (QMS commercial species), NQMSF (fish, non-QMS), QMSR_ONG (QMS reported bycatch (Porifera)), and QMSR_COZ (QMS reported bycatch (Bryozoa)). Fish, non-QMS other species (NQMSF), are not reported as catches were negligible.

Category	Weight (kg)	% Bycatch
NFNQMS	1 028.8	61.4
QMS	86.8	5.2
QMSR_COZ	487.8	29.1
QMSR_ONG	72.7	4.3
	1 676.2	100.0

Table 4: The top ten bycatch species by total weight (Wt, kg), percentage of all bycatch for all regions combined (% all bycatch), and cumulative percentages (Cum%) in 2021. NFNQMS (non-fish, non-QMS, other species not reported), QMS (QMS commercial species), QMSR_ONG (QMS reported bycatch (Porifera)), and QMSR_COZ (QMS reported bycatch (Bryozoa)).

Rank	Category	Species	Code	Wt (kg)	% all bycatch	Cum%
1	QMSR_COZ	*Cinctipora elegans*	CEL	385.7	23.0	23.0
2	NFNQMS	*Astraea heliotropium*	ASH	337.5	20.1	43.1
3	NFNQMS	*Modiolus areolatus*	MAR	210.2	12.5	55.7
4	NFNQMS	*Ophiopsammus maculata*	OMA	158.4	9.5	65.1
5	NFNQMS	*Pyura pachydermatina*	PUP	97.9	5.8	71.0
6	QMSR_COZ	*Othoscuticella fusiformis*	OFU	92.6	5.5	76.5
7	QMS	*Evechinus chloroticus*	SUR	82.9	4.9	81.4
8	NFNQMS	*Pseudechinus_novaezealandie*	PNO	63.6	3.8	85.2
9	QMSR_ONG	*Crella incrustans*	CIN	46.7	2.8	88.0
10	NFNQMS	*Pagurus novizealandiae*	PAG	27.8	1.7	89.7

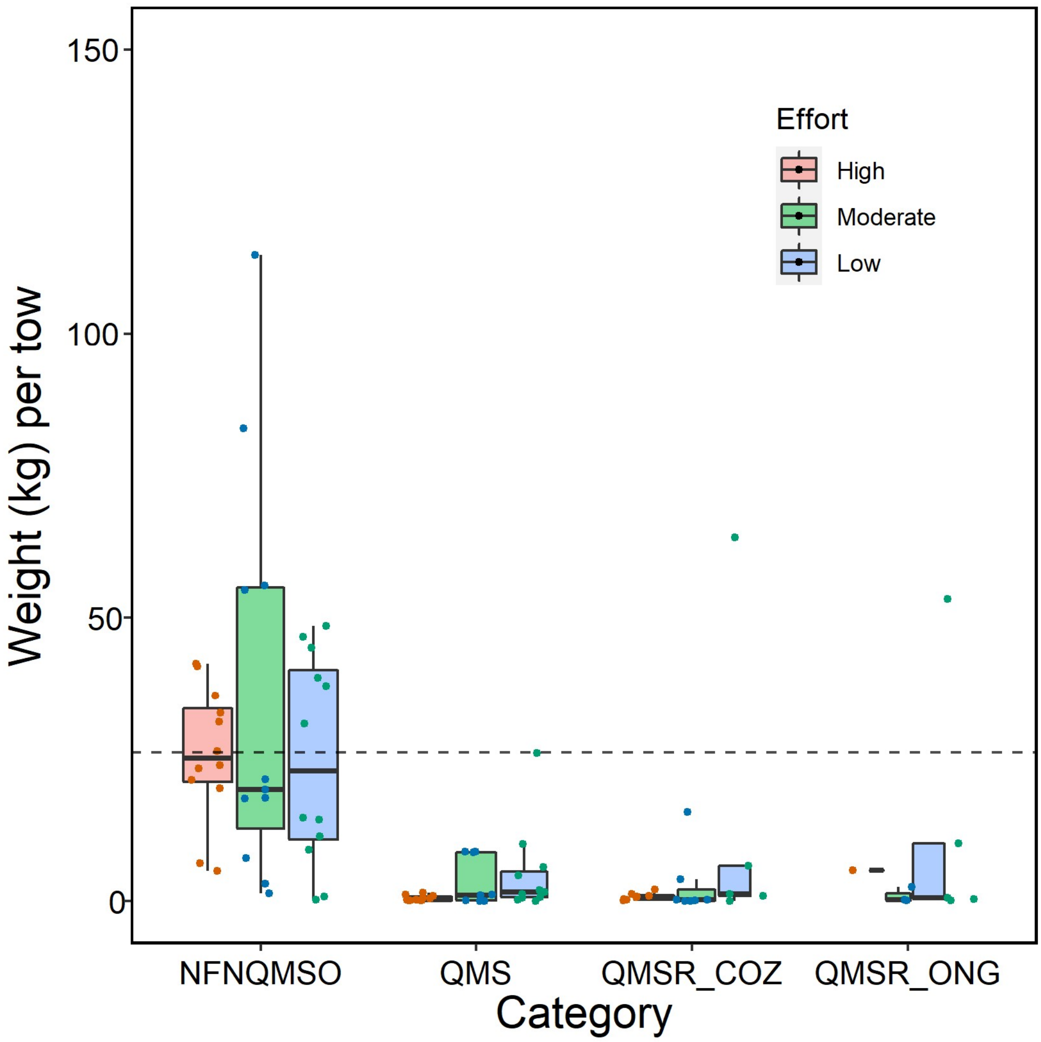

Figure 12: Box plots of the weights of bycatch by category and fishing effort (Effort). Fish non-QMS, other species category were not reported as catches were negligible. One outlier was removed from QMSR_COZ (low fishing effort stratum, CEL, 388.7 kg). Medians shown as solid lines, boxes represent 50th percentiles and whiskers 95th percentiles. The median bycatch weight for all tows is shown as a horizontal black, dashed line (26.2 kg). Outliers represent large catches of *Cinctipora elegans* and *Pyura pachydermatina.*

4.2.2 Bycatch by region

The top 10 bycatch species in each region (Table 5) accounted for 91.8–94.5% of their respective regional totals. Species composition varied by region. Three species *A. heliotropium* (ASH), *O. fusiformis* (OFU), and *M. areolatus* (MAR) together accounted for 59.5% of the bycatch in the western region. Species composition was similar in the central region; *A. heliotropium*, *M. areolatus* and *O. maculata* (OMA) accounted for 64.2% of the bycatch in that region. The combined bycatch weight of the top ten species in the southern region was the highest and most diverse of the four regions (Table 5), and three species collectively accounted for 79.1% of the bycatch: *C. elegans* (CEL) (live and dead branches) accounted for 57.4% of southern bycatch alone and *A. heliotropium* and *M. areolatus* (MAR) for the remaining 21.7%. In contrast, the combined bycatch weight of the top ten species in the eastern region was generally low and the top three species accounted for 66.4% of bycatch: *P. pachydermatina* (PUP) accounted for one third (33.0%), followed by *A. heliotropium* and *Evechinus chloroticus* (SUR) (Table 5). Western fishery areas are characterised by *O. fusiformis*, central areas by *A. heliotropium*, southern areas by *C. elegans*, and eastern areas by *P. pachydermatina. A. heliotropium*, *O. maculata*, and *M. areolatus* are ubiquitous across the fishery area (Table 5).

Table 5: The top 10 bycatch species by weight are required for IEMRS reporting. Percentage of total weight by region for the top 10 bycatch species (see Table A1.1 Appendix 1 for codes and species identifications). Also included are the percentage of the regional bycatch by weight to all regions combined (Reg.%), total weight of bycatch (Total wt., kg), and number of taxa (No. taxa) caught.

Species	Central (%)	Species	East (%)	Species	South (%)	Species	West (%)
ASH	30.9	PUP	33.0	CEL	57.4	ASH	25.7
MAR	19.8	ASH	21.4	ASH	11.5	OFU	17.3
OMA	13.5	SUR	11.9	MAR	10.2	MAR	16.5
PNO	12.0	OMA	10.1	OMA	5.7	CIN	9.1
SUR	5.6	MAR	4.0	MIM	2.8	OMA	8.3
OFU	5.3	PNO	3.9	SUR	2.3	CTO	6.1
PUP	2.7	PAG	3.9	CIN	1.3	SUR	4.5
PAG	1.4	HDR	3.0	PNO	1.2	PAG	1.8
AIN	1.1	AAR	1.9	OFU	1.1	CCM	1.2
NLE	1.0	PRE	1.3	AMA	0.8	NLE	1.2
Reg.%	20.6%		15.7%		40.3%		23.4%
Total wt. (kg)	340.4		260.1		667.1		387.6
No. taxa	47		47		61		55

4.2.3 Bycatch by region and effort

In the western region, low effort grid cells had higher bycatch, followed by high effort grid cells, and the moderate effort grid cells had the lowest bycatch (Figure 13). The low effort strata had higher percentages of sessile epibenthic fauna, mostly *O. fusiformis* (OFU) and *Crella incrustans* (CIN) (Table 6). The bycatch of high and moderate strata had similar dominant assemblages. The high effort strata comprised mostly ubiquitous species *A. heliotropium* (ASH), *M. areolatus* (MAR), and *O. maculata* (OMA) with some *Chondropsis* spp. (CTO), while moderate effort strata also contained ASH, MAR, and OMA (Table 6).

In the central region, high and low effort strata had similarly low bycatch, but bycatch was substantially higher in the moderate effort strata (Figure 13). The dominant bycatch assemblages were similar across all effort strata: High strata, ASH, OMA, and *Pseudechinus novaezealandie* (PNO) accounting for 75.1% of bycatch; moderate strata, ASH, MAR, and PNO accounting for 62.7% of bycatch; and low strata, ASH, OMA, and the sessile stalked ascidian *P. pachydermatina* (PUP) accounting for 70.0% of bycatch (Table 7).

Bycatch in the southern region was generally low in high and moderate fishing effort strata (Figure 13). The mytilid MAR was prominent in all effort strata. The top three species in high effort strata comprised ASH, MAR, and PNO (76.4%); and in moderate effort strata, MAR, OMA, and ASH (66.1%). In low effort strata, a large catch of *C. elegans* (CEL) from a single tow dominated the bycatch of the top three species, followed by MAR and ASH, which combined accounted for 88.8% of the southern low bycatch (Table 8).

Two key features of the eastern region were large stands of *P. pachydermatina*; and a soft, sometimes mobile, gravel substrate. Bycatch weight was broadly similar across the three effort strata (high, moderate, and low) (Figure 13); however, the assemblages differed between strata (Table 9). The top three species in high effort strata were ASH, OMA, and PAG (79.4%); in moderate effort strata PUP (93.7%), *Glycymeris modesta* (GMO, an infaunal bivalve), and ASH (95.5%); and in low effort strata *E. chloroticus* (SUR, 29.9%), OMA, and ASH, (59.2%) (Table 9).

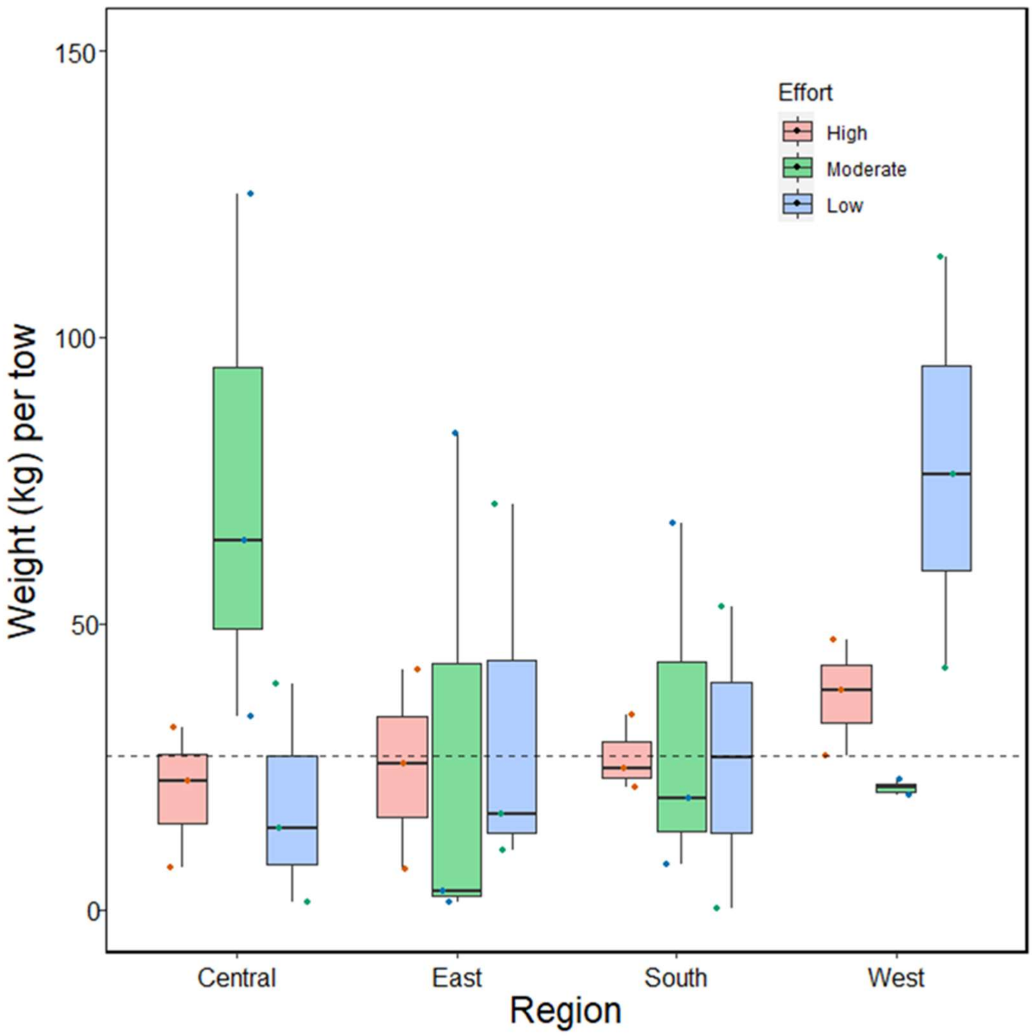

Figure 13: Box plots of the weights of bycatch per tow by region and fishing effort (Effort). Fish non-QMS, other species category were not included as catches were negligible. One outlier was removed from South, low fishing effort stratum (438.9 kg). Medians are shown as solid lines, boxes represent 50th percentiles, and whiskers 95th percentiles. The median bycatch weight for all tows is shown as a horizontal black, dashed line (26.2 kg). Outliers represent large catches of *Cinctipora elegans* and *Pyura pachydermatina*.

Table 6: Percentage of total weight (all three replicate grid cells combined) for the 10 highest ranked bycatch species in the western region, by fishing effort (high, moderate, and low). See Table A1.1 Appendix 1 for codes and species identifications.

Western high		Western moderate		Western low	
Species	Percent	Species	Percent	Species	Percent
ASH	54.7	ASH	38.2	OFU	28.3
MAR	12.3	OMA	30.4	MAR	19.9
OMA	11.0	MAR	8.7	CIN	15.2
CTO	4.8	PAG	4.9	ASH	9.4
PNO	2.4	AMA	4.8	CTO	7.9
PAG	2.0	SUR	2.4	SUR	6.5
NLE	1.6	CCM	1.5	OMA	2.9
CSP	1.5	AAR	1.4	CCM	1.3
SUR	1.3	AIN	1.1	CEL	1.3
ARE	1.3	OHU	1.0	PAG	1.2

Table 7: Percentage of total weight (all three replicate grid cells combined) for the 10 highest ranked bycatch species in the central region, by fishing effort (high, moderate, and low). See Table A1.1 Appendix 1 for codes and species identifications.

Central high		Central moderate		Central low	
Species	Percent	Species	Percent	Species	Percent
ASH	33.7	ASH	29.9	ASH	31.8
OMA	24.3	MAR	24.8	OMA	22.4
PNO	17.0	PNO	12.6	PUP	15.8
MAR	6.2	OMA	8.3	MAR	15.2
OFU	3.4	SUR	7.8	PNO	4.2
PAG	2.5	OFU	7.1	SUR	3.2
TLA	1.9	AIN	1.7	PAG	1.1
TNE	1.9	PAG	1.1	ARE	1.1
NLE	1.8	NLE	1.1	DZE	0.7
PEP	1.2	CIN	1.1	CCM	0.7

Table 8: Percentage of total weight (all three replicate grid cells combined) for the 10 highest ranked bycatch species in the southern region, by fishing effort (high, moderate, and low). See Table A1.1 Appendix 1 for codes and species identifications.

Southern high		Southern moderate		Southern low	
Species	Percent	Species	Percent	Species	Percent
ASH	52.2	MAR	25.4	CEL	77.7
OMA	14.8	OMA	21.5	MAR	7.6
PNO	9.4	ASH	19.1	ASH	3.5
MAR	7.6	SUR	9.2	MIM	2.1
PAG	2.6	MIM	8.5	CIN	1.7
AMA	2.2	AMA	2.0	OMA	1.2
SUR	2.1	PAG	2.0	SUR	1.0
OFU	2.1	TNE	1.7	OFU	0.9
PUP	1.5	OFU	1.3	TLA	0.6
ARE	0.9	NLE	1.3	PEP	0.4

Table 9: Percentage of total weight (all three replicate grid cells combined) for the 10 highest ranked bycatch species in the eastern region, by fishing effort (high, moderate, and low). See Table A1.1 Appendix 1 for codes and species identifications.

Eastern high		Eastern moderate		Eastern low	
Species	Percent	Species	Percent	Species	Percent
ASH	59.4	PUP	93.7	SUR	29.9
OMA	11.0	GMO	0.9	OMA	18.4
PAG	9.0	ASH	0.9	ASH	10.9
AAR	4.5	PAG	0.8	HDR	8.0
PNO	4.1	MAR	0.7	MAR	7.5
MAR	3.4	PNO	0.4	PNO	7.0
SUR	2.4	AAR	0.4	PUP	3.5
ARE	1.0	PEL	0.3	PRE	3.0
PEP	0.7	ARE	0.3	TLA	2.7
PRE	0.7	MIM	0.2	PAG	2.7

4.2.4 Estimated catch by bycatch category and region

Non-fish, non-QMS species (NFNQMS) dominated the bycatch (60.9%) in all regions and effort strata combined (Table 10). NFNQMS also dominated across most across individual regions and effort strata except for the southern and western regions low effort stratum, where large catches of *C. elegans* the bushy bryozoan and *O. fusiformis* dominated the bycatch, and the western region low effort stratum, where bycatch was dominated by *Crella incrustans* and *Chondropsis topsentii*. The percentage of QMS species (fish and non-fish) was generally low (< 8%), except for large catches of *E. chloroticus* in the eastern low effort stratum and the southern moderate effort strata. Fish bycatch was negligible. QMS reportable bryozoans (QMSR_COZ) were largely absent from most regions and effort strata except for the southern low effort (79.2% of bycatch) and western low effort strata (30.6% of bycatch). QMS-reportable sponges (QMSR_ONG) were also largely absent from most regions and effort strata except for the western region, low effort stratum (23.1% of bycatch) (Table 10). Across all regions, high effort strata accounted for 19.9% of the bycatch, moderate effort strata for 27.1%, and low effort strata for 53.0%. For all fishing effort strata combined, the eastern region accounted for the lowest percentage of all bycatch (15.7%), followed by central (20.6%), western (23.4%), and southern (40.3%).

Table 10: Total bycatch weight (kg) and percentage of each category, by region and fishing effort.

Effort	NFNQMS		QMS		QMSR_COZ		QMSR_ONG	
	Total wt (kg)	%	Total wt (kg)	%	Total wt (kg)	%	Total wt (kg)	%
Central region								
High	58.2	94.4	0.2	0.3	3.3	5.3	0.0	0
Moderate	187.6	84.0	17.4	7.8	15.9	7.1	2.5	1.1
Low	53.0	96.1	2.2	3.9	0.0	0	0.0	0
Eastern region								
High	72.6	97.5	1.9	2.5	0.0	0	0.0	0
Moderate	87.7	99.9	0.1	0.1	0.0	0	0.0	0
Low	68.5	70.0	29.3	30.0	0.0	0	0.0	0
Southern region								
High	76.4	95.5	1.8	2.2	1.8	2.3	0.0	0
Moderate	80.7	85.0	9.8	10.3	4.1	4.3	0.4	0.4
Low	86.2	17.5	5.3	1.1	389.9	79.2	10.7	2.2
Western region								
High	104.1	92.5	1.8	1.6	1.3	1.1	5.4	4.8
Moderate	41.2	96.5	1.2	2.8	0.3	0.6	0.0	0
Low	91.2	39.3	16.3	7.0	71.2	30.6	53.7	23.1
All regions								
All	1007.4	60.9	87.3	5.3	487.8	29.5	72.7	4.4

4.2.5 Estimates of bycatch scaled by the numbers of dredge tows

Mean and median weights of all bycatch combined were scaled by the average numbers of tows per stratum (region and fishing effort category) to give estimates of bycatch for the 2020 oyster season (Figure 14 and Table 11). High fishing effort strata accounted for 93.0% of all annual bycatch from the fishery, moderate effort for 6.8%, and low effort strata for 0.16%. The western region had the highest percentage of scaled bycatch (33.2%), followed in order of rank by the central region (28.7%), the southern region (22.8%), and the eastern region (14.2%). These differences most likely reflect the different habitats, species assemblages, and individual species weights within assemblages. Estimates of bycatch scaled by the number of commercial tows in 2020 are given in Table A3.2 (Appendix 3).

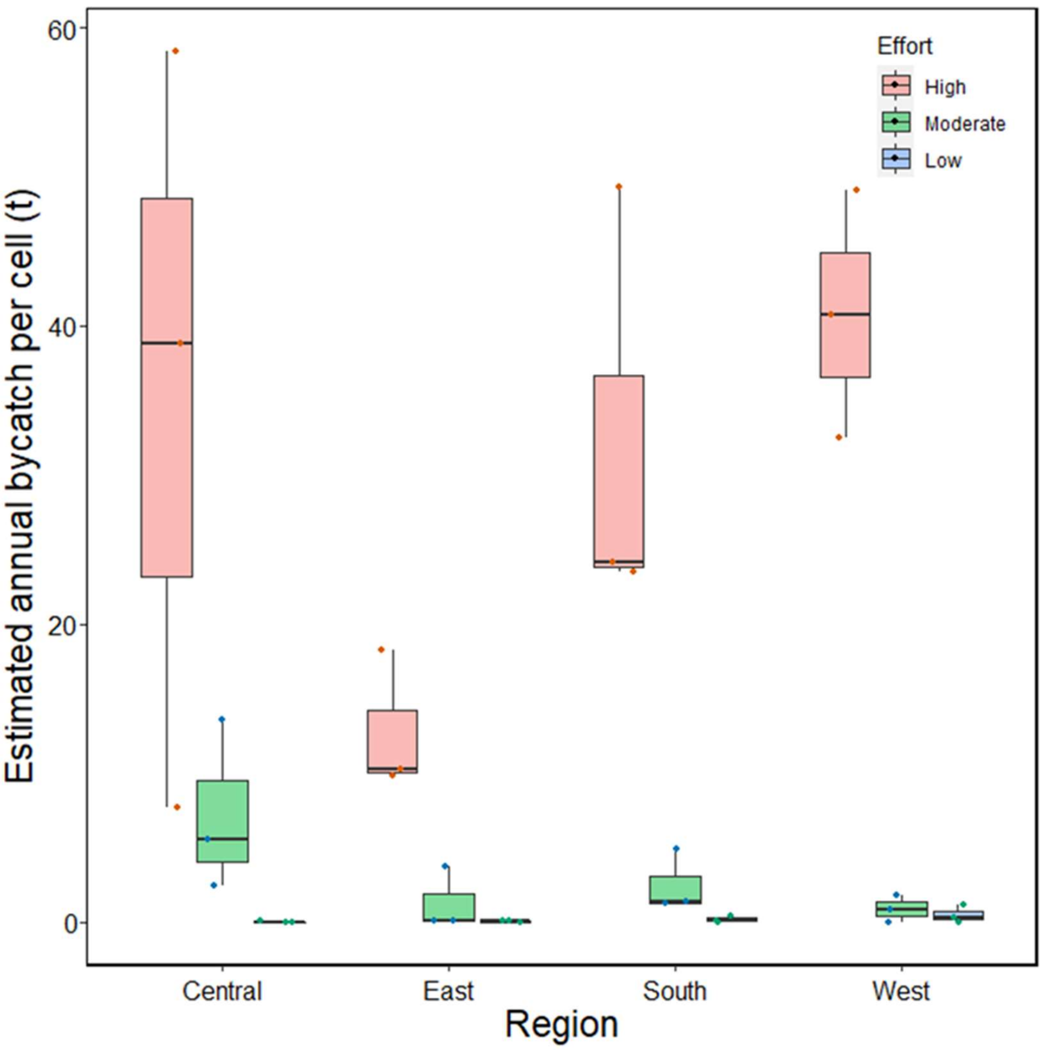

Figure 14: Boxplots of bycatch weight (t) scaled by the number of tows in each grid cell during the 2020 oyster season and shown by region and fishing effort (Effort). Medians are shown as solid lines, boxes represent 50th percentiles, and whiskers 95th percentiles.

Table 11: The weight of 2020 oyster season bycatch, estimated by region (western, central, southern, and eastern) and by fishing effort. Tows 2020 is the average number of tows in each stratum. Average weight for all species combined (Av wt (kg)), median weight (Med wt), 5th and 95th percentiles (5th perc. and 95th perc., respectively). Bycatch 1 (t) is calculated scaling average weight by number of tows, and Bycatch 2 by the median weight. Bycatch 2% gives the percentage of each region and stratum to the estimated total catch from all 36 grid cells (excludes grid cell N22).

Effort	Tows 2020	Av wt (kg	Med wt	5th perc.	95th perc.	Bycatch 1 (t)	Bycatch 2 (t)	Bycatch 2%
Central region								
High	1 530	20.6	22.6	9	30.8	31.52	34.54	25.45
Moderate	89	74.5	64.6	36.8	119.1	6.63	5.75	4.24
Low	1	18.2	14.3	2.7	37	0.02	0.01	0.01
Eastern region								
High	752	24.8	25.5	8.8	40.4	18.65	19.18	14.14
Moderate	39	29.3	3.1	1.6	75.3	1.14	0.12	0.09
Low	1	32.6	16.7	10.9	65.4	0.03	0.02	0.01
Southern region								
High	1 178	26.7	24.6	21.6	33.1	31.45	29.01	21.38
Moderate	99	31.6	19.4	9.1	62.7	3.13	1.92	1.42
Low	1	164.1	53	5.5	400.3	0.16	0.05	0.04
Western region								
High	1 132	37.5	38.4	28.1	46.3	42.45	43.47	32.04
Moderate	62	14.2	19.9	2	22.4	0.88	1.24	0.91
Low	5	77.5	76.1	45.7	110.2	0.39	0.38	0.28

4.3 Oyster discards

In February 2021, the combined survey estimate of mean population size for all four size groups of oysters in the Bonamia survey area was 2379.6 million oysters, an increase of 28.8% from 2020 (1847.6 million oysters). The 2021 population size comprised 801.4 million recruits (in this case all oysters above and including recruit size, i.e., commercial- and recruit-sized combined), 487.0 million pre-recruits, and 1091.2 million small oysters (Michael et al.2022). The reported commercial landings of oysters for the 2020 oyster season (L) were 8.16 million oysters (Fisheries New Zealand extract number "13 717 2019-20 landed oysters", MPI, 15th June 2021).

The dredged recruit-sized catch, Cc, is the total number of oysters above MLS landed on the vessel before sorting of the catch and discards. This was estimated to be 16.1 million oysters, 2% of the recruited population in the Bonamia survey area in 2021 (3.3% in 2020), where L = 8.16 million oysters and PL = 0.506 (see Section 3.3.1). $PL1$ (see Section 3.3.1), from the survey estimates of population sizes in February 2021, and $PL2$, the mean proportion of oysters above MLS that were of commercial size from bycatch sampling, were the same proportion (0.506).

4.3.1 Oyster discards above minimum legal size

The estimate of oysters above MLS discarded (*Nda*) was 8.0 million, or 49.4% of all oysters caught above MLS. *Nda* represented 1.0% of the recruited population in the Bonamia survey area in 2021, fewer than in 2020 (1.5%).

4.3.2 Oyster discards below minimum legal size

Pdb1 was estimated to be 0.663 (1578.2 million oysters below MLS out of 2379.6 million oysters of all sizes) of the population size of all four of the size groups of oysters in the Bonamia survey area (Michael et al. 2022).

Pdb2, the mean proportion of oysters below MSL, from the 37 bycatch tows in February 2021 was 0.665.

Pdb2 was used to estimate the number of oysters below MLS that were discarded (*Ndb*) in the 2020 oyster season, which was 48.1 million. The percentage of discards below MLS of the population of all sized oysters in the Bonamia survey area was 2.0% in 2021 (3.3% in 2020).

4.4 Monitoring of an unfished area

Logbook grid cell N22 (see Figure 11) was selected to be sampled every bycatch sampling year to provide a reference cell for future monitoring of an unfished area. Between 2006 and 2020, only two prospecting tows were reported in grid cell N22 (in 2014). N22 is close to an area that has been constantly fished since 2006, logbook grid cell M18–29 and N19–21.

Dredge catch composition was simple and comprised mainly gravel and shell. The total catch comprised six bins (187.7 kg), of which 21.4 kg (11.6%) were bycatch. The bycatch contained few species (n = 18) and was dominated by mobile species, the ophiuroid *O. maculata* (OMA) and hermit crab *Pagurus novizealandiae* (PAG) (Table 12). Sessile benthic species comprised a relatively low percentage of the bycatch and included the stalked ascidian *P. pachydermatina* (PUP) and mytilid *M. areolatus* (MAR).

Few oysters were caught: 31 commercial-sized, 27 recruit-sized, 30 pre-recruits, and 63 small oysters.

Table 12: Bycatch caught in grid N22, an unfished grid cell in the southern fishery area. All recorded species were presented by weight (kg), total number (Number), percentage of the bycatch by weight (%), and the cumulative percentage by rank (cum%). See Table A1.1 Appendix 1 for species names.

Species	Weight (kg)	Number	Percentage (%)	Cum%
OMA	16.3	646	74.98	74.98
PAG	1.25	125	5.75	80.73
PUP	0.97	7	4.46	85.19
MAR	0.63	24	2.90	88.09
PNO	0.6	72	2.76	90.85
CSP	0.58	6	2.67	93.51
CCM	0.51	2	2.35	95.86
TLA	0.26	1	1.20	97.06
ASH	0.19	3	0.87	97.93
SCA	0.12	1	0.55	98.48
PEP	0.07	3	0.32	98.80
PRE	0.07	2	0.32	99.13
NLE	0.06	6	0.28	99.40
PEL	0.05	1	0.23	99.63
OFU	0.03	0	0.14	99.77
OHU	0.03	3	0.14	99.91
GMO	0.01	1	0.05	99.95
SIN	0.01	1	0.05	100.00

5. DISCUSSION

Bycatch sampling in February 2021 described and quantified the bycatch from dredge catches. There is likely to be a high level of uncertainty around annual estimates of bycatch from the fishery that are scaled up from these data. Whether the catch from each site sampled is representative of the areas fished within grid cells is not known. The bycatch of small-bodied taxa may have been overestimated by the 0.1 kg minimum weight. Bycatch weights by grid cell scaled by the number of tows recorded for the 2020 oyster season, and then extrapolated to the whole fishery, are likely to have high uncertainty.

5.1 Limitations of bycatch sampling

5.1.1 Considerations for bycatch sampling design and methods

The design of bycatch sampling programmes in Foveaux Strait is based on the distribution of fishing between the previous bycatch sampling event and the next sampling event. The spatial resolution of the distribution of fishing data is one square nautical mile, based on the fishers' logbook grid; adopted for IEMRS reporting. The stock assessment survey area was divided into four regions to ensure sampling was representative of the fishery.

The patterns of fishing vary within and between years, and between regions. This variation is primarily driven by distance from port, sea conditions, and tides, and, importantly, oyster size, meat quality, and catch rates. The distribution of relatively high-density oyster patches is primarily driven by the spatio-temporal patterns of disease mortality from *Bonamia exitiosa* (Fu et al. 2016). The spatial variation in the grid cells fished each year make it difficult to compare temporal trends in bycatch in individual grid cells and regions. The likelihood that some grid cells in each region will not be consistently sampled will reduce the ability to investigate the sustainability of localised, sessile epibenthic communities.

Criteria for the selection and stratification of grid cells by fishing effort (number of tows) for sampling are well established. The highest effort grid cells are selected first in each region, followed by the moderate effort grid cells, and finally, low or no effort grid cells. All grid cells are selected as close as possible to each other in each region, to best represent homogeneous habitats and bycatch assemblages. Because low effort grid cells are relatively rare, adjacent no effort grid cells are occasionally chosen to ensure replicates represent, as much as possible, homogeneous habitats and bycatch assemblages.

The one square nautical mile grid cells represent a large area. Commercial fishers use short duration, elliptical tows to maintain their vessels over localised high-density patches of oysters ('oyster beds'). Fishing mostly occurs in a small portion of a grid cell. A randomly allocated location within a grid cell has a high chance of not sampling the area fished, even in cells with high fishing effort. This increases substantially for low effort cells that may have only received one or two fishing events. Plausible reasons why grid cells were not fished could include fishers avoiding complex biogenic areas, or that Bonamia mortality has reduced oyster densities below economic levels.

Vessel tracks recorded at high spatial resolution, either by logging data from the vessels GPS system or increasing the frequency of position fixing (high ping rate) used by the Fisheries New Zealand vessel monitoring system, could accurately delineate the elliptical tows within the grid cells fished. These spatial fine-scale data would greatly improve quantitative estimates of bycatch from the fishery; and reduce misinterpretation of these data when inferring changes to bycatch and the potential effects of fishing.

5.1.2 Monitoring unfished areas

In 2020, the Fisheries New Zealand Shellfish Working Group recommended a few grid cells in unfished areas be sampled each survey to establish baselines of bycatch and oysters, and to investigate how they may respond to fishing and the effects of storms.

Dedicated research programmes, rather than bycatch sampling studies, should be used to delimit biogenic areas so that their composition and extent is well defined. There are also fishery independent data on bycatch from surveys of the oyster fishery and drift video of the seabed of Foveaux Strait that could identify areas with sensitive benthic taxa. However, oyster surveys and commercial attempt to fishing avoid biogenic areas. Drift camera and video sampling could describe and delimit these areas to inform fisher-led strategies for avoidance, and to understand how different areas respond to fishing and storms.

An assessment of the sustainability of different communities could inform priorities for research e.g., *Pyura pachydermatina* is the dominant sessile taxon in eastern and some central and southern fishery areas. *Pyura pachydermatina* is a rapid coloniser and grows rapidly (22 cm in length in its first year after settlement, K. Michael, NIWA, unpublished data) and is likely to be resilient to fishing and natural disturbance. Conversely, sponge and bryozoan communities may or may not be as productive and how sustainable these communities are in Foveaux Strait represents a significant knowledge gap.

5.1.3 Analysis

Commercial fishers use short duration, elliptical tows, and dredges are landed washed, i.e., dipped in and out of the sea to remove sand and gravel and to reduce the volume of bycatch. Small taxa are unlikely to be well represented in dredge contents during commercial fishing. Bycatch sampling uses straight-line tows landed without washing. The dredge contents give quantitative descriptions of bycatch and presence/absence data for small taxa. Fishery independent sampling is likely to overestimate fishery bycatch but give better descriptions of benthic communities than commercial bycatch.

Bycatch is recorded by weight, to satisfy IEMRS reporting requirements, and to allow for the bycatch of colonial species to be quantified. Many individual taxa are small and of a light weight; there may be

50 ophiuroids per kg compared with 3 gastropods per kg. Samples were weighed to 0.1 kg, which may overestimate the weight of some bycatch taxa. Bycatch weight is further over-estimated by scaling to tow level and then to estimates of annual bycatch.

Where random tows fall within areas with dense epibenthic fauna, especially sessile species such as *Cinctipora elegans, P. pachydermatina, Crella incrustans*, and *Chondropsis* spp. dredge saturation greatly reduces sampling efficiency and the dredge ceases fishing early in the tow. Moreover, large catches of individual species, such as the large catch of *C. elegans* (live and dead colonies) in a single tow from the southern low stratum (Figure 15) have considerable influence on averages used for scaling bycatch sampling to fishery estimates. *Cinctipora elegans* is particularly problematic because live colonies are inseparable from dead hash, and so the use of their combined weight leads to a gross overestimate of live bycatch. Fishing in these areas is highly unlikely as both dredge saturation and negligible catches of oysters make fishing these areas uneconomic; however, there are no criteria to exclude these data from analysis. Using medians rather than means reduces the effect of outliers on the estimates of bycatch. However, if these catches occurred in high fishing effort strata, the effects on scaling to fishery bycatch would be substantial.

Figure 15: A large catch of *Cinctipora elegans* (live and hash) from a tow in the southern low stratum.

5.2 Oyster discards and bycatch

5.2.1 Oyster discards

The exploitation rate of recruit-sized oysters in the OYU 5 fishery in 2021 is about 1% of the recruited population, 0.8% in 2020. At such a low exploitation rate, the effects of oyster discards above and below MLS are unlikely to have any effect on the stock. All size groups of oysters are increasing rapidly. Estimates of the number of oysters above and below minimum legal size (MLS) which are discarded are likely to be overestimates.

In 2021, the number of recruit-sized oysters were rebuilding rapidly after a period of high mortality due to *B. exitiosa* (2013–2015) and low recruitment (2010–2015). The estimate of oyster discards above MLS assumed all oysters between a size of 58–64 mm in diameter are returned to sea; however, a large proportion of oysters in this size range are likely to be retained in the eastern fishery area where the oysters are smaller and generally have better meat quality than other areas. Numbers of discards above MLS depend on the levels of high grading and where fishers target their commercial activities. Fishing locations are in part determined by the weather and tides, catch rates, and oyster meat quality. Approximately 8.0 million oysters above MLS were discarded in 2020; that represents 1.0% of the recruit-sized oyster population in the Bonamia survey area alone in 2021. Incidental mortality of these discards is expected to be low, less than 2% (Cranfield et al. 1997).

The increase in recruitment since 2016 has resulted in a relatively high number of oysters below MLS; however, the proportions of oysters below MLS in 2021 (66.4%) were similar to 2020 (71.3%). The number of oysters below MLS discarded in the 2020 oyster season is 48.1 million. The estimate of oyster discards below MLS assumed fishing effort was homogeneous across the fishery area; however, fishers avoid areas with large numbers of small oysters. The percentage of discards below MLS to the population of all sized oysters in the Bonamia survey area is 2.0%. Cranfield et al. (1997) found juvenile oyster discard mortality was approximately 7%. In contrast, natural mortality of 0+ spat may be up to 98% in the first winter (Cranfield 1979).

5.2.2 Bycatch

In Foveaux Strait, benthic taxa are likely well adapted to the high-energy environment and their recolonisation, and succession processes could be reasonably quick. Benthic communities vary across the fishery area; and comprise epibenthic communities that are well described (e.g., Rowden et al. 2007), and an abundant infaunal community mainly comprised of *Oxyperas elongatum*, *Panopea smithii*, *Glycymeris modesta*, *Tucetona laticostata*, and *Tawera spissa*.

Michael (2022) summarised information on two conflicting hypotheses about oyster habitat, drivers of oyster production, and the potential effects of fishing. This summary includes the distribution of benthic communities within the fishery area, the association between oysters and epifaunal reefs in Foveaux Strait, and the distribution of oyster beds and their persistence through 150 years of dredging.

Data from the 1960s and from the mid-1990s to the present provide evidence for a new hypothesis, that oysters are much more productive in areas with very little epifauna and where sediments are occasionally mobile. In these areas, oysters are likely to have less competition for available settlement substrata and less predation and over colonisation by other benthic taxa than on complex epifaunal reefs. Oysters on simple habitats with occasionally mobile sediments are therefore likely to have better recruitment to the population, better survival and growth including better meat condition, allowing high density localised populations to develop.

Complex biogenic areas, especially those with large, sessile, erect epibenthic fauna such as *Crella incrustans*, *Chondropsis* spp., *Pyura pachydermatina*, and *Cinctipora elegans* and *Modiolus areolatus* are avoided by fishers (Hill et al. 2010). These areas are not considered oyster fishery areas; dredge saturation is instantaneous, filling the dredge with high volumes of bycatch with few if any oysters that take much longer to sort and therefore the areas are uneconomic to fish. Moreover, oysters in complex biogenic areas tend to have poor meat condition (Stead 1971) and therefore of lower commercial value. Grid cells subject to low fishing effort may be due to the poor meat quality of oysters rather than low oyster density or high levels of bycatch.

Bycatch composition and volume by fishing effort need to be viewed in the context of likely mismatches in locations between where commercial fishing occurred and where the random bycatch sampling locations fell. Grid cells recording high and moderate fishing effort in 2020, and sampled in 2021, contained mainly mobile, ubiquitous species: *Astraea heliotropium*, *Ophiopsammus maculata*, *Evechinus chloroticus*, *Pseudechinus novaezealandie*, and *Pagurus novizealandiae*, often in high percentages. Sessile species in these strata included *Modiolus areolatus* and *Pyura pachydermatina*, and small quantities of *Chondropsis* spp. Grid cells recording low or no fishing effort in 2020 had substantial catches of sessile benthic fauna that usually comprised a single species, depending on area fished. Bycatch comprised one of: *Cinctipora elegans* (southern region), *Othoscuticella fusiformis* (western region), *Crella incrustans* (central region), and *Pyura pachydermatina* (eastern region).

5.3 Objectives for future bycatch sampling

The main objective of the Foveaux Strait oyster (OYU 5) bycatch sampling programme is to provide data on bycatch and oyster discards for IEMRS reporting. The more accurately the fished area can be defined, the more representative bycatch sampling will be of the fishery. Characterising the bycatch of oyster dredging is fundamental to investigating the sustainability of key bycatch taxa. Provided bycatch sampling is well targeted to the areas fished, key mobile and sessile epibenthic fauna will be identified (e.g., *Cinctipora elegans*, *Pyura pachydermatina*, *Chondropsis* spp., *Crella incrustans*, and *Modiolus areolatus*) and, over time, provide data on spatio-temporal patterns in their abundance. Information on bycatch survival, biology, and ecology is also required to ensure sustainability of these species.

If an objective of this bycatch sampling is to delimit and avoid sensitive habitats, this is best done by using the extensive survey data available, further supported by drift video surveys to delimit and characterise these habitats. If the objective of this sampling is to infer the effects of fishing on benthic communities, the current bycatch sampling design assumes that low or no fishing effort grid cells are considered as part of the commercial fishery because they occur within the stock areas. These areas are assumed to represent typical fishing areas before they have been fished. Low or no fishing effort grid cells may or may not have complex biogenic communities (e.g., N22, characterised by mobile sediments), and these grid cells may or may not have been fished. However, inferences about the effects of fishing become greatly uncertain unless supported by information on the fine spatial distribution of fishing and the distribution of sessile benthic communities. Additionally, sediment transport during storms can change benthic landscapes at fishery-scale. Any effects of oyster dredging need to be considered in the context of natural disturbance.

If information on the different benthic assemblages, their distributions, and overlaps with oyster dredging, and the effects of fishing are specifically required by managers, these questions should be addressed by specific research programmes. Some key questions about the drivers of oyster production, such as the relationship between oysters and sessile benthic epifauna (e.g., *Cinctipora elegans*, Cranfield et al. 1999) are being addressed by the Fisheries New Zealand research programme OYS2020-03.

6. MANAGEMENT IMPLICATIONS

Schedule 6 of the Fisheries Act 1996 states "a commercial fisher may return a dredge oyster of legal size to the waters from which it was taken if the oyster is likely to survive". Other targeted oyster stocks (OYS 4, OYS 7, and OYS 7C) are in Schedule 6, but OYU 5 and OYS 10 are not. The mortality of oysters above MLS is low (Cranfield et al. 1997), suggesting that OYU 5 could be included in Schedule 6.

Oyster discards represent a relatively small proportion of the oyster population, and their incidental mortality is thought to be low. Oyster discards are unlikely to have a detectable effect on stock size and recruitment to the fishery.

The footprint of the fishery is small within the stock assessment survey area (1070 km^2) and the stock area (approximately 3000 km^2). Within the relatively small area fished, the uncertainty around whether the locations sampled for bycatch have been fished may limit inferences that can be made by these data for management. Although most bycatch is returned to sea within 10 minutes, little is known about the post-release survival of bycatch species. The survival of the most abundant species caught in highly fished areas (*Astraea heliotropium*, *Ophiopsammus maculata*, *Modiolus areolatus*, *Pseudechinus novaezealandie*, and *Pagurus novizealandiae*) has not been quantified. Neither has survival of sessile species such as *Pyura pachydermatina*, *Othoscuticella fusiformis*, *Cinctipora elegans*, *Chondropsis* spp., and *Crella incrustans* which may be more vulnerable to mortality.

Little is known about the spatial and temporal patterns of recolonisation and over colonisation by epibenthic species. Bycatch survey data suggest that they recolonise quickly. Establishing a time series of bycatch data stratified by fishery region and fishing effort will assist to disentangle the effects of fishing, storms, and biological processes that shape benthic communities in the oyster fishery.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

7.1 Future bycatch surveys

The reliability of bycatch data from the OYU 5 fishery will be dependent on accurately defining the areas fished within individual grid cells. Because of the unique, short duration (~ 5 mins) elliptical commercial tows and the reduction in speed to about 2.0–3.0 knots while dredging, high-resolution vessel tracks will be able to define the areas fished. Software for the analysis of these data is readily available.

Sampling effort for future bycatch surveys should reflect the spatial patterns of commercial fishing between bycatch surveys, i.e., if bycatch surveys are undertaken every two years, the effort data from the previous two oyster seasons should be used to allocate grid cells. Bycatch surveys should cover all the area where commercial fishing occurs. Future survey designs acknowledge that the relative levels of fishing effort for high, moderate, and low categories will differ between fishery regions. Bycatch sampling should remain consistent with the 2020 survey, to enable comparisons across surveys. For example, catch composition resolution should be kept the same in future surveys, i.e., all taxa should be recorded with rounded minimum weights of 0.1 kg and counts recorded for each non-colonial species.

The frequency of surveys needs to be agreed. A bycatch survey may not need to be repeated every year, but the most likely number of years between surveys needs to be evaluated after the results of several bycatch surveys are compared. Bycatch surveys were undertaken in 2019, 2020, 2021, and now in 2022. Because of the extensive oyster stock assessment survey planned for 2023, no bycatch survey is scheduled for 2023.

7.2 Survival of discards

Cranfield et al. (1997) estimated the incidental mortality of different sizes of oysters dredged and returned to sea. Short-term survival of different sizes of oysters discarded by the commercial fishery could be estimated from caged experiments. Longer term survival could be estimated from tagging trials that would also provide estimates of growth from recaptured oysters.

The short-term survival of common bycatch species discarded by the commercial fishery could also be estimated from cage and tagging experiments.

8. ACKNOWLEDGEMENTS

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APPENDIX 1: BYCATCH SPECIES NAMES AND CODES

Table A1.1: Foveaux Strait non-fish bycatch species and species codes.

Code	Species	Code	Species	Code	Species
AAR	*Alcithoe arabica*	**EUN**	*Eunicidae*	**PAV**	*Haliotis virginea*
AIN	*Allostichaster insignis*	**GAS**	Gastropods other	**PCA**	*Pyura carnea*
ALP	*Ophiocomidae 1*	**GLM**	*Perna canaliculus*	**PEL**	*Oxyperas elongatum*
AMA	*Aulacomya atra maoriana*	**GMO**	*Glycymeris modesta*	**PEP**	*Pentagonaster pulchellus*
AMI	*Asterodon miliaris*	**GUM**	*Goniocidaris umbraculum*	**PHU**	*Pseudochinus huttoni*
ARE	*Apatopygus recens*	**HDR**	hydroid	**PIG**	*Congiopodus leucopaecilus*
ASH	*Astraea heliotropium*	**HMO**	*Hemerocoetes monopterygius*	**PNO**	*Pseudechinus novaezealandie*
ATU	*Argobuccinum pustulosum tumidum*	**MAR**	*Modiolus areolatus*	**PRE**	*Patiriella regularis*
BAR	*Balanus decorus*	**MCO**	*Mesopeplum convexum*	**PSE**	*Pseudodistoma spp.*
BCO	*Parapercis colias*	**MGR**	*Modelia granosa*	**PUP**	*Pyura pachydermatina*
BNO	*Barbatia noveaezealandiae*	**MIM**	*Modiolarca impacta*	**RCA**	*Rhyssoplax canaliculata*
BOT	*Botryloides leachi*	**MNO**	*Metacarcinus novaezealandie*	**RFO**	*Retehornera foliacea*
BRI	*Ophiocomidae 2*	**NCO**	*Neothyris compressa*	**SCA**	*Pecten novazealandiae*
BUL	*Eleotridae*	**NEC**	*Nectocarcinus* sp.	**SHO**	*shrimp*
CAG	*Celleporaria agglutinans*	**NEL**	*Nemertesia elongata*	**SIN**	*Sigapatella novaezelandiae*
CAL	*Calliostoma* spp.	**NLE**	*Neothyris lenticularis*	**SLU**	*Sea louse*
CAN	*Cominella nassoides*	**NTO**	*Notomithrax* sp.	**SMO**	*Sclerasterias mollis*
CAO	*Cardita aoteana*	**NUD**	*Nudibranchs*	**SSC**	*Australostichopus mollis*
CCM	*Coscinasterias muricata*	**OCT**	*Pinnoctopus cordiformis*	**SUR**	*Evechinus chloroticus*
CCR	*Callochiton crocinus*	**OFU**	*Othoscuticella fusiformis*	**TAL**	*Talochlamys*
CEL	*Cinctipora elegans*	**OHU**	*Octopus huttoni*	**TEW**	*Tewara cranwellae*
CGF	*Gastroscyphus hectoris*	**OMA**	*Ophiopsammus maculata*	**TLA**	*Tucetona laticostata*
CHA	*Charonia* sp.	**OYS**	*Ostrea chilensis*	**TNE**	*Tetrocycloecia neozelanica*
CIN	*Crella incrustans*	**OYSC**	*Commercial*	**TRC**	*Eurynolambrus australis*
CPO	*Crypotoconchus porosus*	**OYSL**	*Recruit*	**TSP**	*Tawera spissa*
CSP	*Cabestana spengleri*	**OYSM**	*Pre-recruit*	**VPU**	*Venericardia purpurata*
CTO	*Chondropsis topsentii*	**OYSS**	*Small*	**WPO**	*Anomia trigonopsis*
DPA	*Dactyllia palmata*	**PAG**	*Pagurus novizealandiae*	**YME**	*Xymene pumilus*
DZE	*Dosina zelandica*	**PAL**	*Pseudechinus albocinctus*	**YSL**	*Darwinella oxeata*
ENO	*Eudoxochiton nobilis*				

APPENDIX 2: DELINEATION OF FISHERY REGIONS

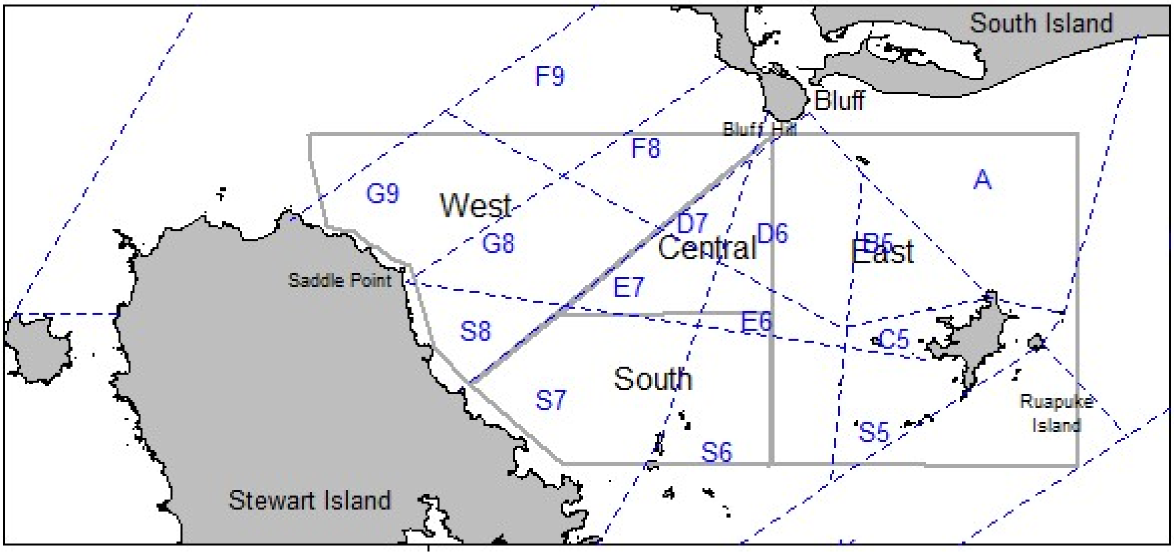

Figure A2.1: The OYU 5 fishery area with the four commercial fishery regions (Western, Central, Southern, Eastern shown as grey lines and labelled in black text) and the Foveaux Strait Oyster statistical reporting areas (dashed blue lines labelled in blue text).

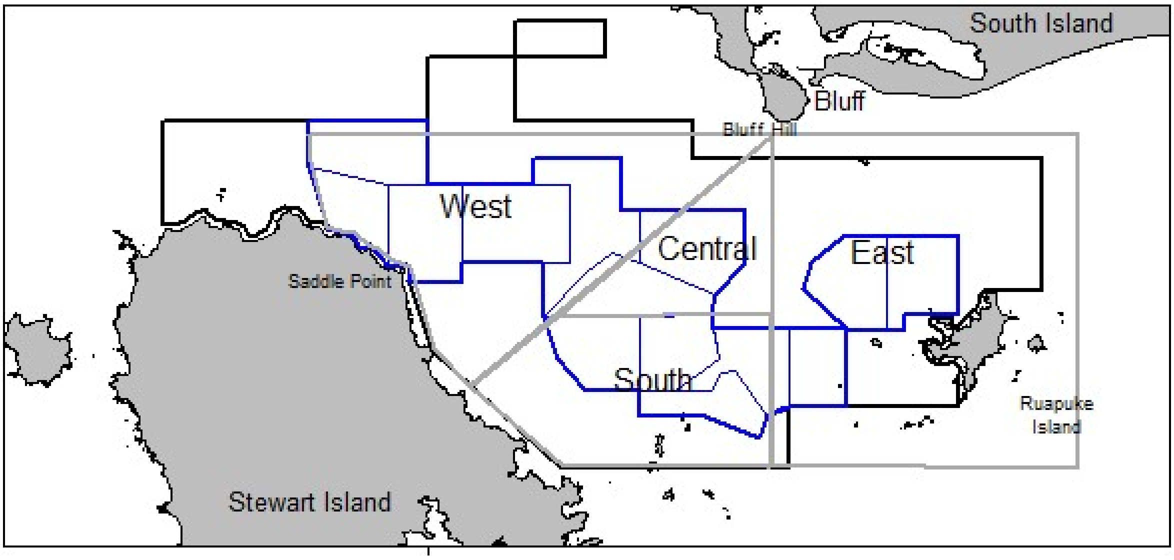

Figure A2.2: The OYU 5, 2007 stock assessment survey area (black lines), the boundary of the Bonamia survey area (blue lines) with the four commercial fishery regions (Western, Central, Southern, Eastern shown as grey lines and labelled in black text).

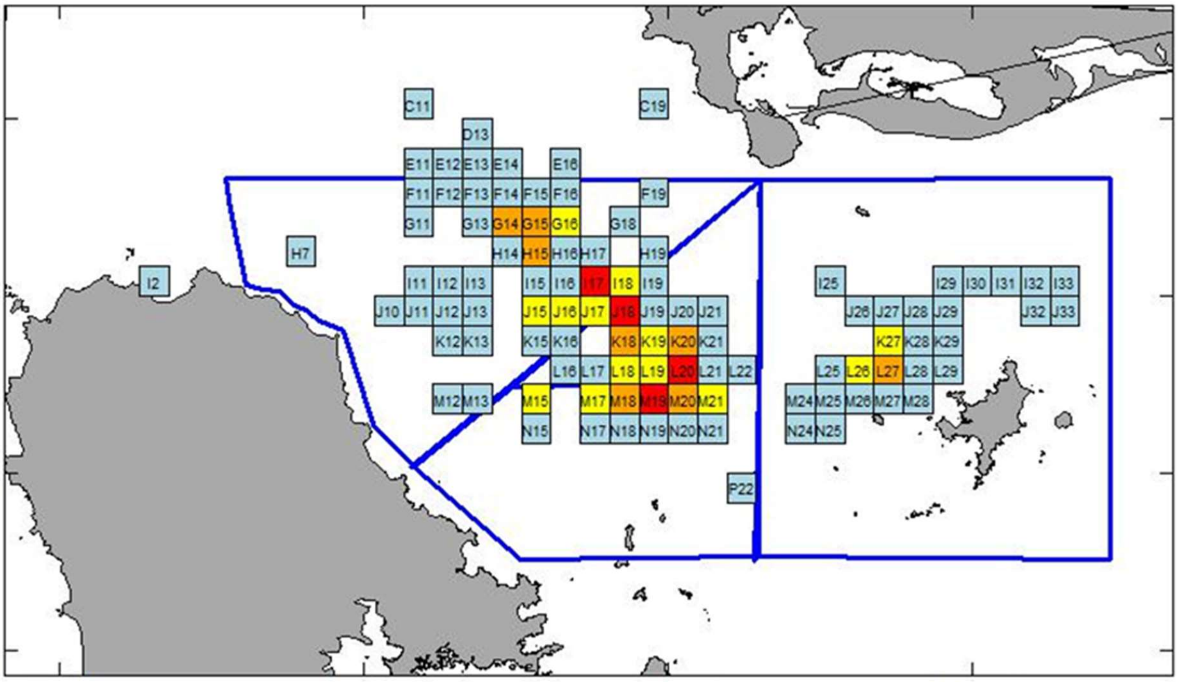

Figure A2.3: The distribution of catch from the 2020 Foveaux Strait oyster season as a percentage of the total annual catch. Grid cells are colour coded red for 5–10%, orange 3–5%, yellow 1–3%, blue <1%, and grid cells where no fishing took place are blank. The four commercial fishery regions (Western, Central, Southern, Eastern) are delimited by blue lines.

APPENDIX 3: BYCATCH SUMMARY BY CATEGORY, CLASS, AND SPECIES.

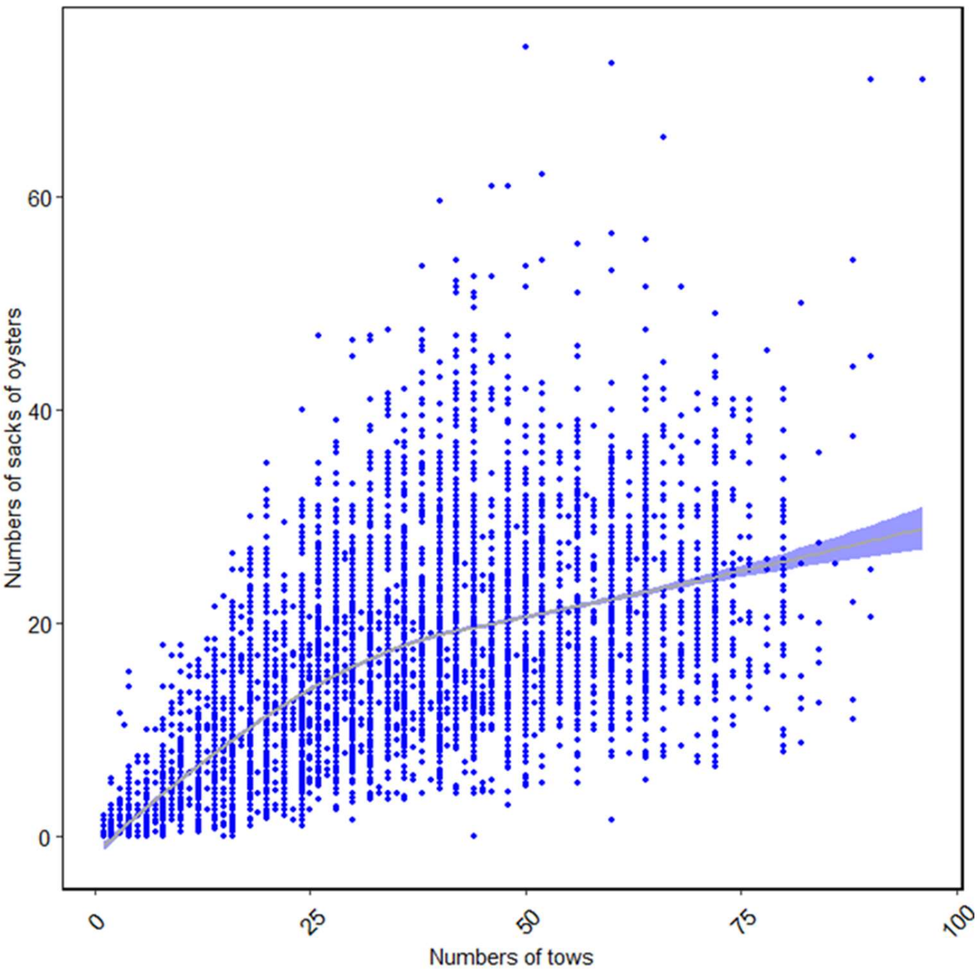

Figure A3.1: Scatter plot of number of dredge tows per fishers' logbook grid cell per day against the number of sacks of oysters (*Ostrea chilensis*). Correlation described by loess smoother ± 1SD.

Table A3.1: Total weight (kg) by category (see Table 2 Fisheries New Zealand 2018), class and species, and the percentages of total bycatch weight by category (% Category) and by all bycatch (% Bycatch). Categories are: NFNQMS (non-fish, non-QMS, other species not reported as catches were negligible), QMS (QMS commercial species), QMSR_COZ (QMS reported bycatch (Bryozoa)) and QMSR_ONG (QMS reported bycatch (Porifera)). NQMSF (fish, non-QMS) bycatch was negligible and not shown

Category	Class	Species	Weight (kg)	% category	% Bycatch
NFNQMS	Gastropoda	ASH	337.5	32.8	20.1
NFNQMS	Bivalvia	MAR	210.2	20.4	12.5
NFNQMS	Ophiuroidea	OMA	158.4	15.4	9.5
NFNQMS	Ascidiacea	PUP	97.9	9.5	5.8
NFNQMS	Echinoidea	PNO	63.6	6.2	3.8
NFNQMS	Malacostraca	PAG	27.8	2.7	1.7
NFNQMS	Bivalvia	MIM	23.3	2.3	1.4
NFNQMS	Rhynchonellata	NLE	11.9	1.2	0.7
NFNQMS	Bivalvia	AMA	11.5	1.1	0.7
NFNQMS	Asteroidea	PEP	9.0	0.9	0.5
NFNQMS	Hydrozoa	HDR	8.2	0.8	0.5
NFNQMS	Asteroidea	CCM	7.7	0.8	0.5
NFNQMS	Bivalvia	TLA	7.1	0.7	0.4
NFNQMS	Asteroidea	AIN	6.2	0.6	0.4
NFNQMS	Echinoidea	ARE	6.2	0.6	0.4
NFNQMS	Gastropoda	AAR	5.7	0.6	0.3
NFNQMS	Gastropoda	CSP	4.1	0.4	0.2
NFNQMS	Asteroidea	PRE	4.1	0.4	0.2
NFNQMS	Cephalopoda	OHU	3.5	0.3	0.2
NFNQMS	Gastropoda	CAL	3.1	0.3	0.2
NFNQMS	Polyplacophora	RCA	2.1	0.2	0.1
NFNQMS	Bivalvia	MCO	2.0	0.2	0.1
NFNQMS	Bivalvia	GMO	2.0	0.2	0.1
NFNQMS	Malacostraca	NTO	1.8	0.2	0.1
NFNQMS	Bivalvia	SCA	1.0	0.1	0.1
NFNQMS	Gastropoda	ATU	0.9	0.1	0.1
NFNQMS	Polyplacophora	CPO	0.9	0.1	0.1
NFNQMS	Ophiuroidea	ALP	0.7	0.1	0.0
NFNQMS	Bivalvia	VPU	0.7	0.1	0.0
NFNQMS	Malacostraca	NEC	0.7	0.1	0.0
NFNQMS	Bivalvia	PEL	0.6	0.1	0.0
NFNQMS	Gastropoda	SIN	0.6	0.1	0.0
NFNQMS	Polychaeta	EUN	0.6	0.1	0.0
NFNQMS	Hexanauplia	SLU	0.5	0.1	0.0
NFNQMS	Malacostraca	TRC	0.5	0.1	0.0
NFNQMS	Cirripedia	BAR	0.5	0.0	0.0
NFNQMS	Bivalvia	TAL	0.5	0.0	0.0
NFNQMS	Ascidiacea	PSE	0.4	0.0	0.0
NFNQMS	Polyplacophora	ENO	0.4	0.0	0.0

Table A3.1: Continued.

Category	Class	Species	Weight (kg)	% category	% Bycatch
NFNQMS	Bivalvia	BNO	0.4	0.0	0.0
NFNQMS	Bivalvia	TSP	0.4	0.0	0.0
NFNQMS	Actinopterygii	TEW	0.3	0.0	0.0
NFNQMS	Gastropoda	MGR	0.3	0.0	0.0
NFNQMS	Hydrozoa	NEL	0.3	0.0	0.0
NFNQMS	Rhynchonellata	NCO	0.3	0.0	0.0
NFNQMS	Echinoidea	PAL	0.3	0.0	0.0
NFNQMS	Actinopteri	BUL	0.2	0.0	0.0
NFNQMS	Echinoidea	PHU	0.2	0.0	0.0
NFNQMS	Actinopteri	CGF	0.2	0.0	0.0
NFNQMS	Bivalvia	YME	0.2	0.0	0.0
NFNQMS	Ascidiacea	BOT	0.2	0.0	0.0
NFNQMS	Malacostraca	SHO	0.2	0.0	0.0
NFNQMS	Actinopterygii	HMO	0.2	0.0	0.0
NFNQMS	Ascidiacea	PCA	0.2	0.0	0.0
NFNQMS	Asteroidea	SMO	0.1	0.0	0.0
NFNQMS	Demospongiae	YSL	0.1	0.0	0.0
NFNQMS	Bivalvia	WPO	0.1	0.0	0.0
NFNQMS	Gastropoda	PAV	0.0	0.0	0.0
NFNQMS	Gastropoda	CAN	0.0	0.0	0.0
NFNQMS	Ophiuroidea	BRI	0.0	0.0	0.0
NFNQMS	Gastropoda	NUD	0.0	0.0	0.0
NFNQMS	Asteroidea	AMI	0.0	0.0	0.0
NFNQMS	Bivalvia	CAO	0.0	0.0	0.0
NFNQMS	Polyplacophora	CCR	0.0	0.0	0.0
NFNQMS	Gastropoda	CHA	0.0	0.0	0.0
NFNQMS	Gastropoda	GAS	0.0	0.0	0.0
NFNQMS	Echinoidea	GUM	0.0	0.0	0.0
NFNQMS	Malacostraca	MNO	0.0	0.0	0.0
NFNQMS	Actinopterygii	PIG	0.0	0.0	0.0
Subtotal			1 028.8		61.4

Category	Class	Species	Weight (kg)	% category	% Bycatch
QMS	Echinoidea	SUR	82.9	95.5	4.9
QMS	Holothuroidea	SSC	2.3	2.7	0.1
QMS	Actinopteri	BCO	0.8	1.0	0.0
QMS	Bivalvia	DZE	0.3	0.4	0.0
QMS	Cephalopoda	OCT	0.2	0.3	0.0
QMS	Bivalvia	GLM	0.2	0.2	0.0
Subtotal			86.8		5.2

Table A3.1: Continued.

Category	Class	Species	Weight (kg)	% category	% Bycatch
QMSR_COZ	Gymnolaemata	CEL	385.7	79.1	23.0
QMSR_COZ	Gymnolaemata	OFU	92.6	19.0	5.5
QMSR_COZ	Gymnolaemata	CAG	3.6	0.7	0.2
QMSR_COZ	Gymnolaemata	TNE	3.3	0.7	0.2
QMSR_COZ	Gymnolaemata	RFO	2.6	0.5	0.2
Subtotal			487.8		29.1

Category	Class	Species	Weight (kg)	% category	% Bycatch
QMSR_ONG	Demospongiae	CIN	46.7	64.2	2.8
QMSR_ONG	Demospongiae	CTO	25.0	34.4	1.5
QMSR_ONG	Demospongiae	DPA	1.0	1.4	0.1
Subtotal			72.7		4.3
Grand total			1 676.2		100.0

Table A3.2: Mean bycatch weight (kg) per tow (By wt) for all species combined by Region, Fishing effort (Effort) and logbook grid cell (Grid cell) from the February 2021 bycatch sampling. For each logbook grid cell, the number of tows (Tows) from the fishers' 2020 oyster season (1 March to 31 August) logbook data, the number of vessel days (Vessel days) and the percentage of the 2020 annual catch (% Catch) are provided. Bycatch (kg) from each grid cell for the 2020 oyster season estimated by scaling up the mean bycatch per tow by the number of tows in each grid cell (Ann_by) is also provided.

Region	Effort	Grid cell	Tows	Vessel days	% Ann_catch	By_wt	Ann_by
Central	High	J18	1 844	51	7.7	31.7	58 395.8
Central	High	L20	1 720	41	7.3	22.6	38 823.8
Central	High	K18	1 027	26	3.3	7.5	7 651.2
Central	Moderate	L21	108	6	0.4	125.1	13 513.0
Central	Moderate	J19	86	5	0.5	64.6	5 554.2
Central	Moderate	K16	72	1	0.2	33.8	2 430.7
Central	Low	J21	2	1	0	0.7	1.4
Central	Low	L22	2	1	0	14.3	28.7
Central	Low	K21	0	0	0	39.5	0.0
Subtotal	-		7 413	204	28	339.7	

Region	Effort	Grid cell	Tows	Vessel days	% Catch	By_wt	Ann_by
East	High	L27	1 420	32	4.8	6.9	9 854.8
East	High	K27	434	10	1.3	42.0	18 241.0
East	High	I32	402	11	0.9	25.5	10 252.6
East	Moderate	N25	44	2	0.1	83.3	3 665.2
East	Moderate	J33	40	2	0.1	3.1	123.6
East	Moderate	I33	32	1	0.1	1.4	45.4
East	Low	I25	2	1	0	10.3	20.6
East	Low	K25	2	1	0	16.7	33.4
East	Low	J25	0	0	0	70.8	0.0
Subtotal	-		4 228	135	12.7	260.1	

Region	Effort	Grid cell	Tows	Vessel days	% Catch	By_wt	Ann_by
South	High	M19	1 445	44	6.6	34.1	49 254.3
South	High	M18	1 133	30	3.8	21.3	24 146.5
South	High	M20	957	28	4.5	24.6	23 565.2
South	Moderate	N19	156	4	0.7	8.0	1 244.9
South	Moderate	N20	72	2	0.3	67.5	4 860.0
South	Moderate	N21	69	4	0.2	19.4	1 338.9
South	Low	O18	1	1	0	53.0	53.0
South	Low	O22	1	1	0	0.2	0.2
South	Low	P20	1	1	0	438.9	438.9
Subtotal	-		5 262	159	20.8	633.0	

Table A3.2: Continued.

Region	Effort	Grid cell	Tows	Vessel days	% Catch	By_wt	Ann_by
Central	High	I17	1 510	35	6.8	27.0	40 733.8
Central	High	G15	1 040	27	4	47.2	49 100.5
Central	High	H15	846	25	3.2	38.4	32 486.4
Central	Moderate	F15	79	4	0.5	22.7	1 794.2
Central	Moderate	F11	67	3	0.4	0.0	0.0
Central	Moderate	F14	41	2	0.1	19.9	816.7
Central	Low	I12	10	1	0.2	114.0	1 139.9
Central	Low	H13	4	1	0.1	76.1	304.4
Central	Low	I13	0	0	0	42.3	0.0
Subtotal	-		10 150	306	38.5	313.5	
Total						1 622.8	