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Estimates of bycatch and oyster discards from the Foveaux Strait oyster fishery (OYU 5) in February 2022

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The Integrated Electronic Monitoring and Reporting System (IEMRS) 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 2022 as part of the Fisheries New Zealand programme OYS2020-01. Sampling was undertaken in collaboration with the Bluff Oyster Management Company Limited which provided the survey vessel, the OYU 5 survey dredge, and crews to assist with the survey. The bycatch survey used the design and methods agreed to by the Fisheries New Zealand Shellfish Working Group in November 2020. Fishery independent bycatch sampling was undertaken after the February 2022 oyster and *Bonamia exitiosa* (Bonamia) survey.

Sampling estimated oyster discards above and below minimum legal size (MLS). Live bycatch in the dredge contents was described and quantified in the five categories required for reporting: non-fish non-Quota Management System (QMS) species, QMS commercial species, non-QMS fish, and QMS reported bycatch for Porifera (sponges) and Bryozoa (corals). 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, and subsamples were scaled to total catch weight.

Commercial landings in 2021 were 7.6 million oysters. Sixty-seven logbook grid cells were commercially fished, and 26 001 tows were recorded, similar to 2020. About 64.3% of the effort (numbers of tows) was in the western region with 21.2%, 9.1%, and 5.4% from central, southern, and eastern regions, respectively. Oyster discards above MLS were approximately 7.5 million, or 49.4% of all oysters caught above MLS. These represented 1.3% of the recruit-sized population in the Bonamia survey area in 2022, more than in 2021 (1.0%), and fewer than in 2020 (1.5%). Discards below MLS were 55.5 million, and 2.7% as a percentage of the population of all sized oysters in the Bonamia survey area in 2022 (compare with 2.0% in 2021 and 3.3% in 2020).

Bycatch was less diverse in 2022 than in previous surveys, and no large catches of sponges, bryozoans, or stalked ascidians were taken. Live bycatch was on average 4.0% of the total unsorted catch. The top ten species ranked by weight (86.2% of bycatch in 2022) were non-fish non-QMS that are ubiquitous throughout the fishery area. Two of these species, *Astraea heliotropium* and *Modiolus areolatus,* accounted for 51.1% of all bycatch. QMS species accounted for 11.4%; kina (*Evechinus chloroticus*) accounted for 10.9%. Bycatch of bryozoans and porifera combined accounted for a further 2.4% of all bycatch. The bushy bryozoan *Othoscuticella fusiformis* accounted for most of this bycatch. Bycatch by each region and fishing effort were mostly similar and generally comprised mobile species *A. heliotropium*, *Ophiopsammus maculata*, *E. chloroticus*, and *Pagurus novaezealandie*, and the sessile species *M. areolatus* accounted for the highest catches across all effort strata and regions.

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

These survey bycatch estimates are consistent with bycatch data recorded in fishers' logbooks which reflect relatively simple benthic habitats of sand, gravel, and shell with relatively few patches of erect epibenthic fauna in fished areas.

Higher resolution vessel track data could greatly enhance sampling design, and bycatch survivorship trials could better determine the fate of taxa returned to the sea.

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.

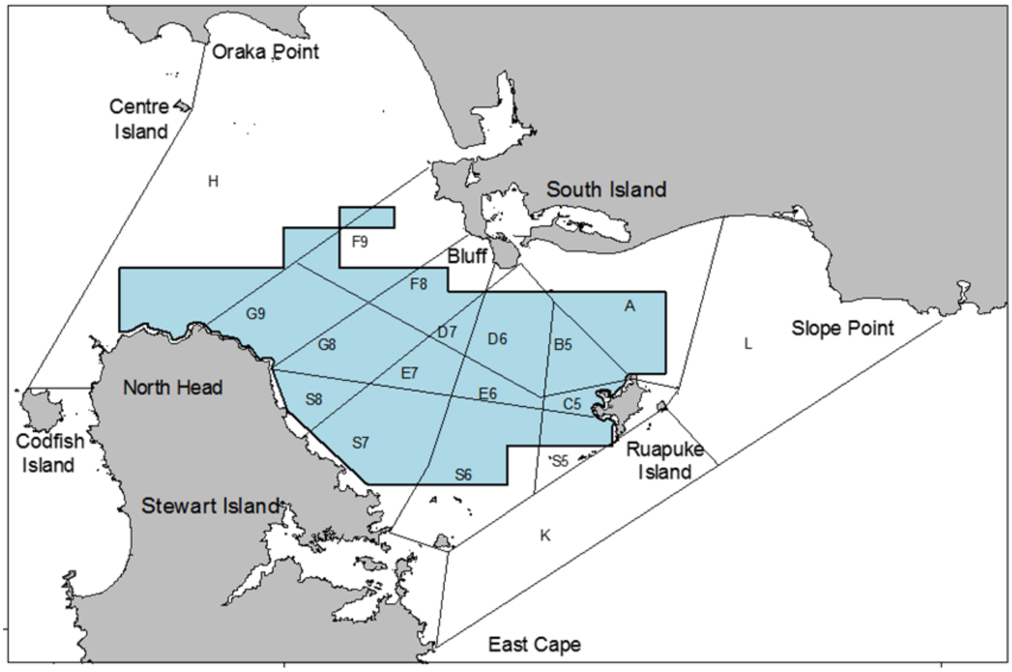

Figure 1: Foveaux Strait (OYU 5) stock boundary and oyster fishery statistical reporting areas (black text in the blue polygons), and the outer boundary of the 2007 stock assessment survey area (blue shade) encompassing almost all the commercial fishery.

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 transitioned 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 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. 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.

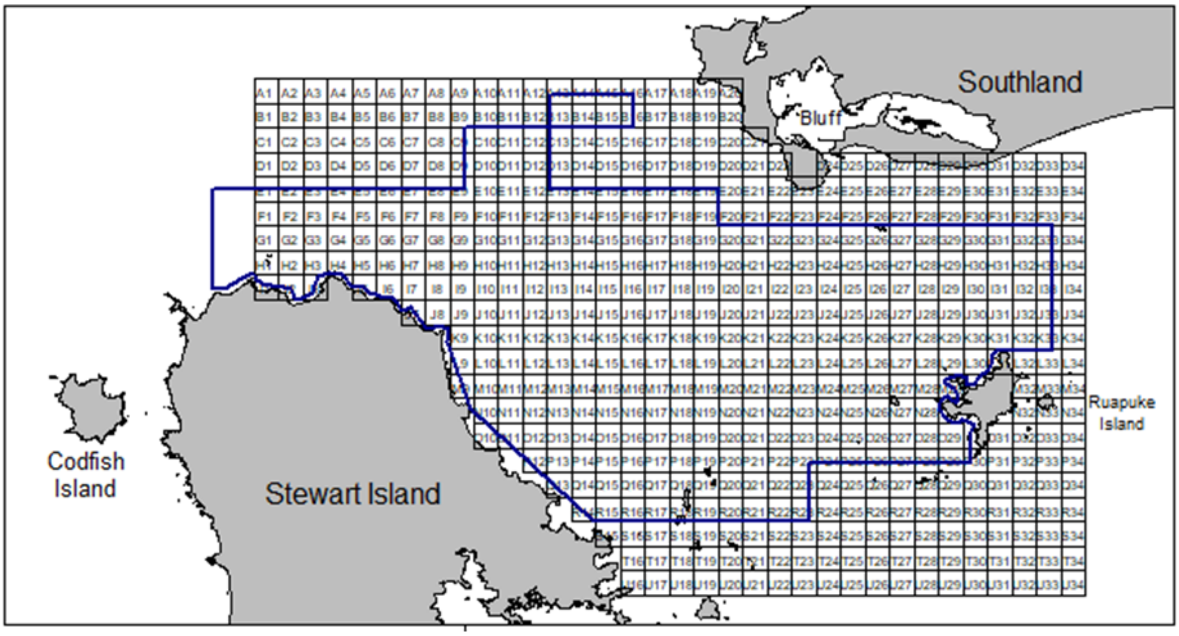

Figure 2: The Foveaux Strait oyster (OYU 5) logbook reporting grid cells (in black) and boundary for the stock assessment survey area (blue lines).

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 assemblages 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 and 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).

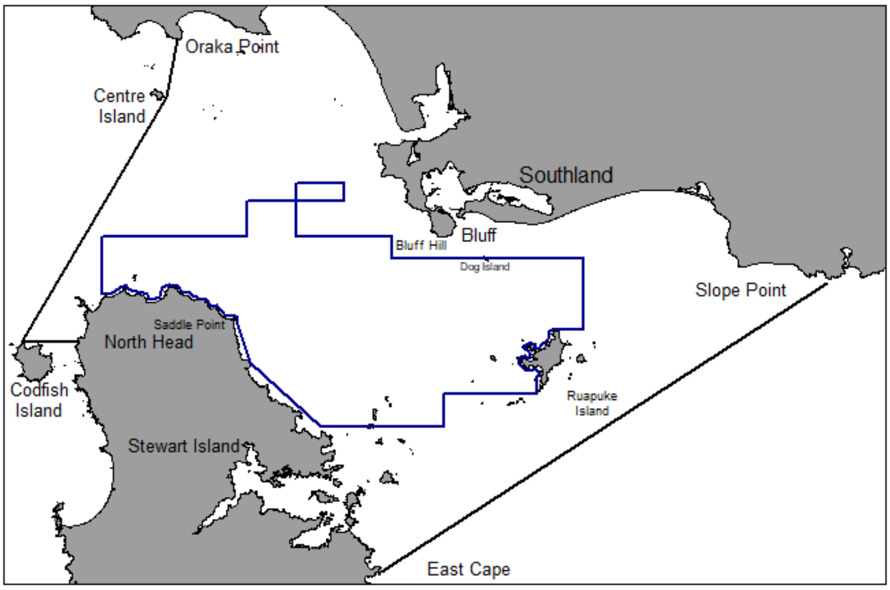

Figure 3: Foveaux Strait oyster stock (OYU 5) boundaries (black lines) and the outer boundary of the 2007 stock assessment survey area (blue line) that encompasses the commercial fishery.

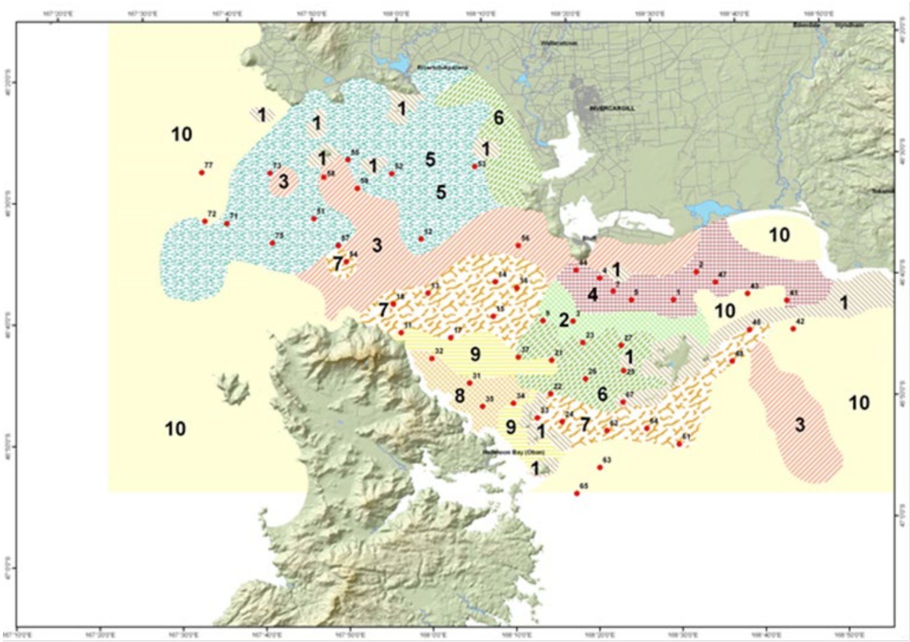

Figure 4: The distribution of subjective habitat classes based on sediment composition, structure, and stability from video transects and the sediment map of Cullen & Gibb (1966). 1, rocky patch reef with epifauna, usually surrounded by sand and fine gravels; 2, flat gravels with clean shell (usually *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.

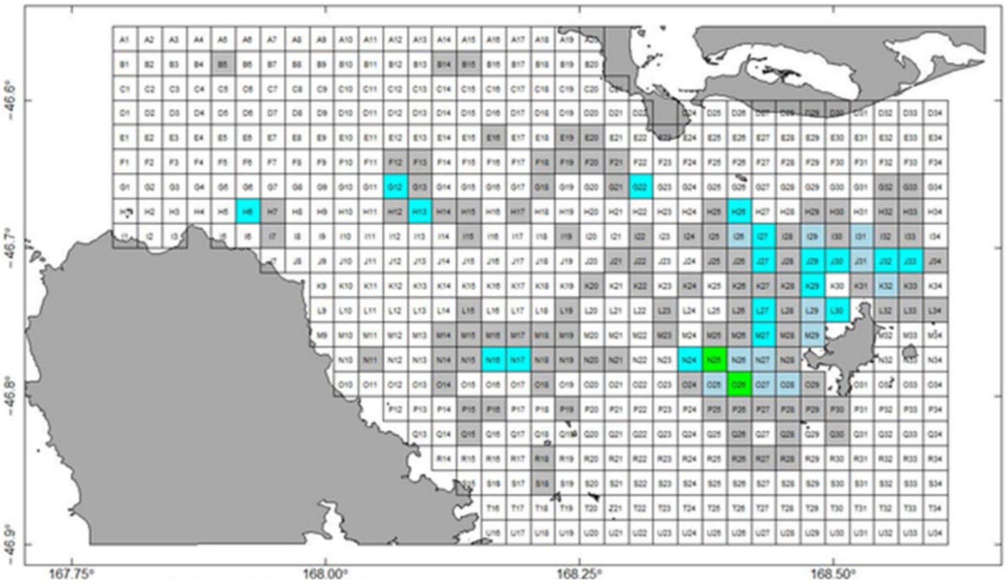

Figure 5: The distribution of dredge tows per grid cell as a percentage of total dredge tows for the 2006 oyster season, from oyster fishers' logbook data. Grid cells shaded green ≥ 3.0% & < 5.0%, blue ≥ 2.0% & < 3.0%, cyan ≥ 0.1% & < 2.0%, and grey > 0% & < 0.1%. No tows are shown as white grid cells.

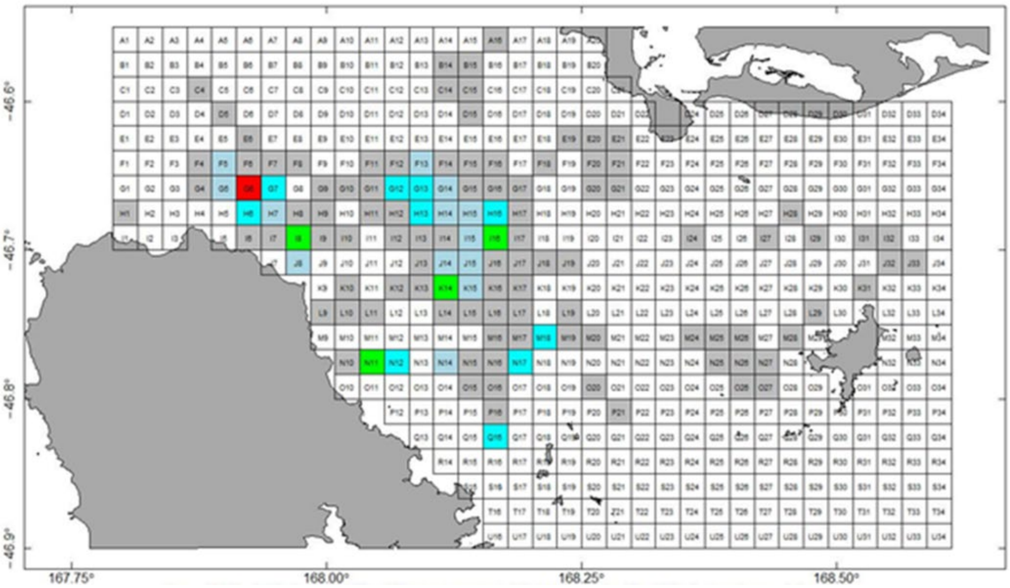

Figure 6: The distribution of dredge tows per grid cell as a percentage of total dredge tows for the 2007 oyster season, from oyster fishers' logbook data. Grid cells shaded red ≥ 5.0% & < 10.0%, green ≥ 3.0% & < 5.0%, blue ≥ 2.0% & < 3.0%, cyan ≥ 0.1% & < 2.0%, and grey > 0% & < 0.1%. No tows are shown as white grid cells.

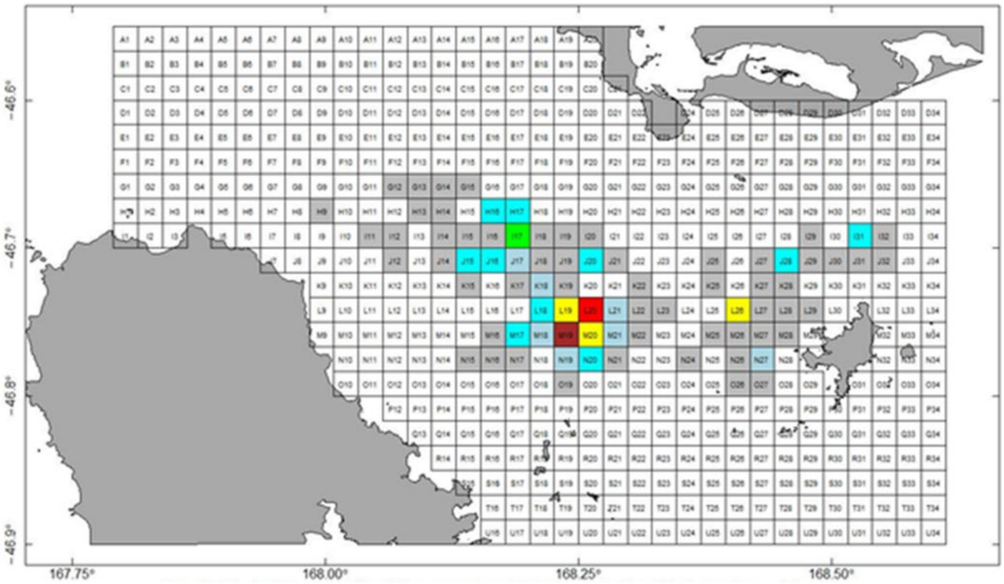

Figure 7: The distribution of dredge tows per grid cell as a percentage of total dredge tows for the 2015 oyster season, from oyster fishers' logbook data. Grid cells shaded brown > 10%, red ≥ 8.0% & < 10.0%, yellow ≥ 5.0% & < 8.0%, green ≥ 3.0% & < 5.0%, blue ≥ 2.0% & < 3.0%, cyan ≥ 0.1% & < 2.0%, and grey > 0% & < 0.1%. No tows are shown as white grid cells.

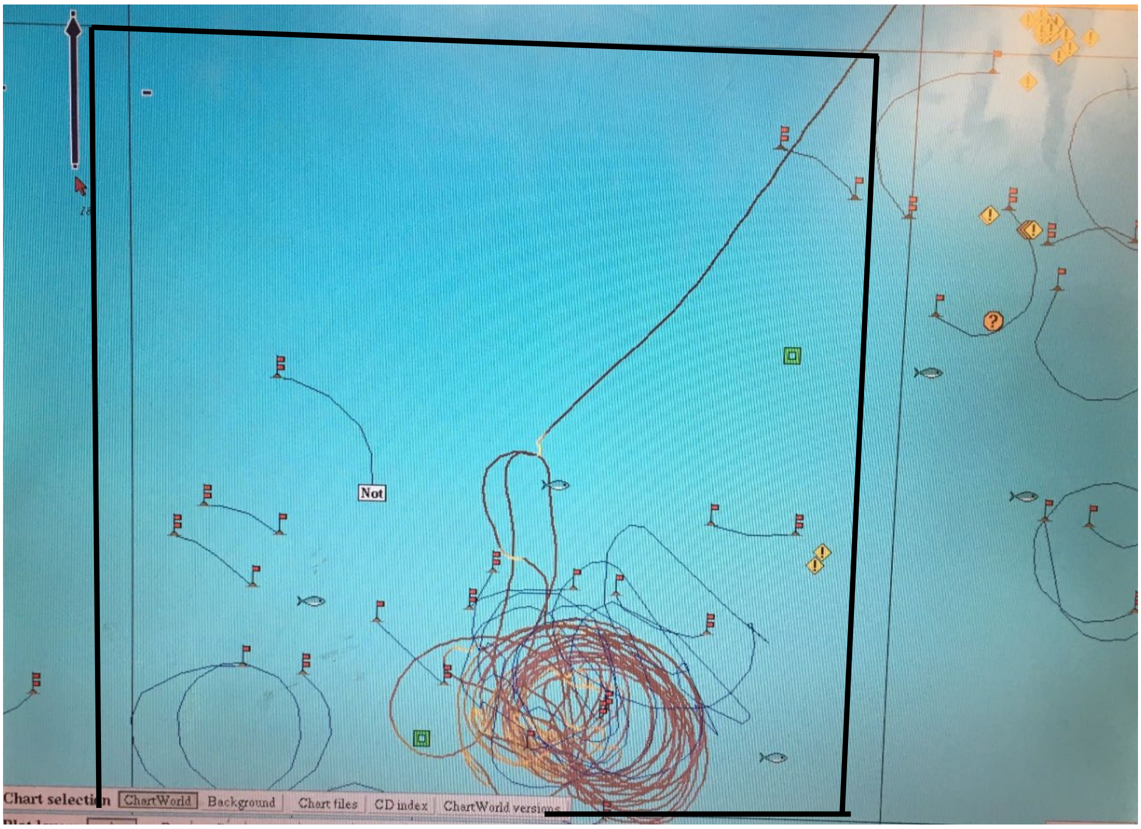

Figure 8: A screen grab of an oyster vessel's circular tracks while fishing a grid cell. Fishing is often concentrated in a relatively small proportion of the overall grid cell area. Slightly curved lines show the locations of sand banks, marked at either end with one or two flags.

1.5 Summary of results from bycatch sampling in February 2019, February 2020, and February 2021

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 for the last stock assessment survey in 2017. 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.

Oyster discards were estimated from survey estimates of population size by four size groups, see Section 3.3.1 below. The number of oysters below minimum legal size (MLS) returned to the sea and discards of oysters above MLS were 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, represented 44% of legal-sized catch.

Bycatch per tow (total catch) was low (median 29.8 kg) and much of this could 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 (SCC 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.

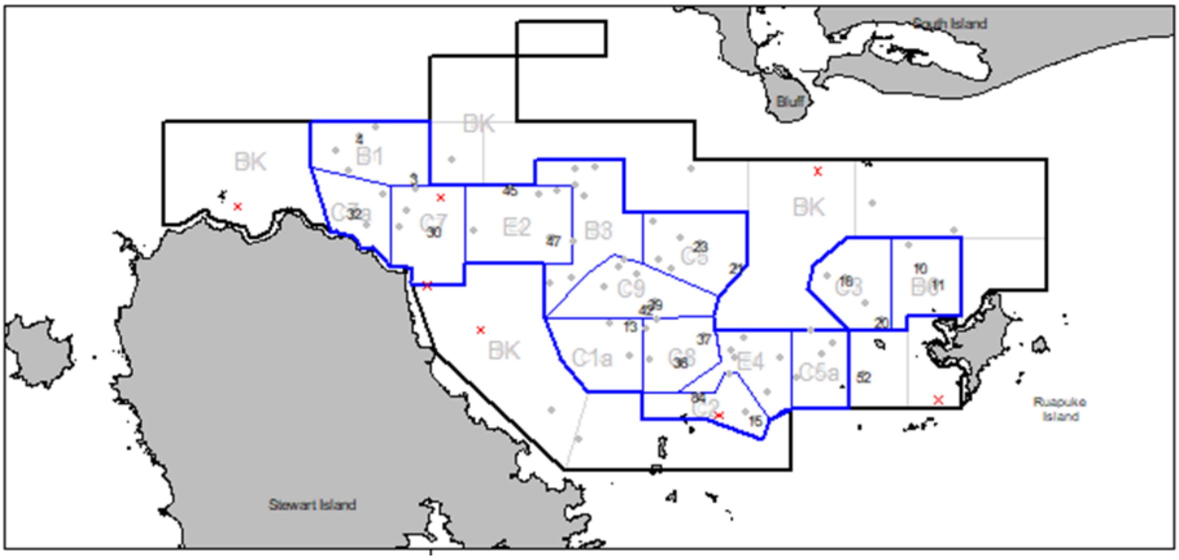

Figure 9: The 2019 survey area with the 2007 survey boundary shown as a heavy, black outer line, the Bonamia survey area as a heavy blue line, and the 2019 Bonamia survey strata shown as thin blue lines. The remaining stock assessment survey strata (light grey lines) in the large background stratum were 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.

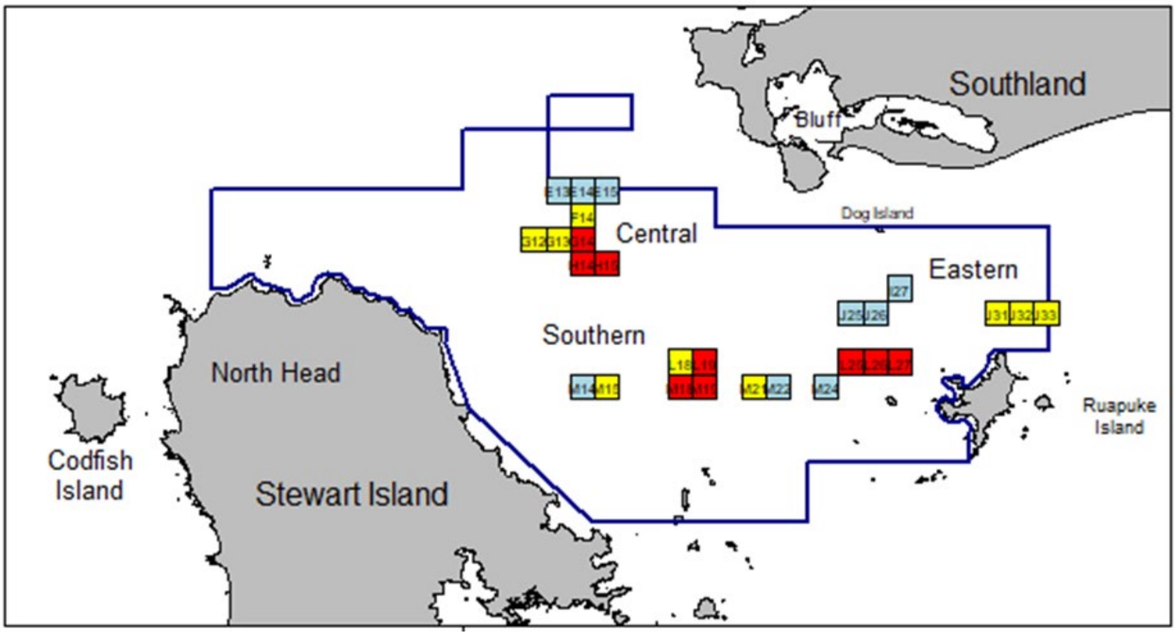

Figure 10: The location of grid cells sampled for bycatch in February 2020. The 27 tows were stratified by three regions (Eastern, Southern, and Central), three fishing effort categories (high, red; medium, yellow; and low, blue), with a single random tow in each of three replicate grid cells in each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

1.5.2 Bycatch sampling in 2020

Bycatch sampling was again undertaken in February 2020, between the 2019 and 2020 oyster seasons. The 2020 sampling estimated oyster discards above and below MLS and described and quantified macrofaunal bycatch species (counts and weights for individual species, and weights only for colonial species) from dredge sampling (Michael 2022a). 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 its total weight in the catch by the proportion of bins subsampled to the total number of bins.

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, and QMSR_ONG (Sponges), and 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 2022a). 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.

Oyster discards (see Section 3.3.1) above MLS 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 MLS 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.

1.5.3 Bycatch sampling in 2021

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. Twelve 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. Three grid cells were sampled in each stratum (region and fishing effort, Figure 11), 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. Grid cell N22 (Figure 11, green cell) was selected to provide a reference cell for future monitoring of an unfished area. Sampling estimated oyster discards and bycatch using the same sampling methods as for the February 2020 bycatch sampling.

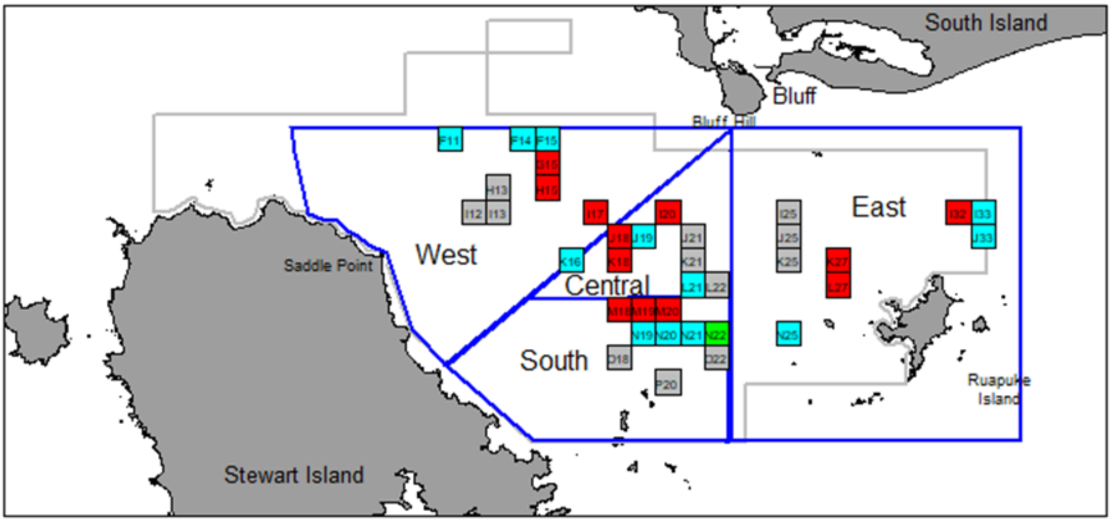

Figure 11: The four fishery regions (West, Central, South, and East) shown as blue lines, the stock assessment survey area shown as grey lines, and selected fishers' logbook grid cells that represent high (red), moderate (cyan), and low (grey) fishing effort. Grid cell N22 selected as an unfished cell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

Median bycatch of all species (excluding oysters) across all tows (n = 37) in 2021 was 26.2 kg (5th to 95th 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 the branching bryozoan *Cinctipora elegans* (CEL). Mean weight of individual species was less than 3.0 kg per tow, except for CEL. Non-fish non-QMS species accounted for 61.4% of bycatch, of which 47.9% comprised four species, in order of rank: *A. heliotropium* (20.1%); *M. areolatus* (12.5%; *O. maculata* (9.5%); and *P. pachydermatina* (5.8%) of all bycatch (all regions combined). These four species are the same as for the top ranked species in 2020. Bycatch of

QMS species was small. Kina *Evechinus chloroticus* accounted for 4.9% of all bycatch (all regions combined) and was mostly confined to the eastern fishery area. Other QMS species, including sea cucumbers (*Australostichopus mollis*) accounted for less than 0.1% of the bycatch. QMS fish bycatch was negligible. Bycatch of bryozoans (COZ) and porifera (ONG) combined accounted for a further 33.4% of all bycatch in 2021, which was much higher than in 2020 (4.4%). Bycatch of *C. elegans* (comprised live colonies and dead hash) accounted for 23% of all bycatch from a single station in the southern region, low effort strata. 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.

Commercial landings of oysters for the 2021 oyster season were 8.16 million oysters. Oyster discards (see Section 3.3.1) above 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%). Estimated discards of oysters below MLS 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 was 2.0% in 2021 (3.3% in 2020).

2. OBJECTIVES

2.1 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 2022, completing Objective 3. This bycatch sampling used the same methods as for the February 2021 sampling programme.

2.2 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 design for bycatch sampling in 2022 was the same as that for February 2021 (Michael 2022b) and was developed in collaboration with the Shellfish Working Group and Fisheries New Zealand (Marine Pomarède and Marco Milardi). The survey was 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 2022 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.

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, 1960–1990) reporting by the statistical areas, survey strata, and fishers' logbook data from the 2021 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 2021 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

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. 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 (see Figure A2.4, Appendix 2). 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 for the February 2022 sampling is given in Table 1.

Cells with high, moderate, and low or no fishing effort were identified from the 2021 oyster season fishers' logbook data that account for almost all fishing effort. Sixty-seven logbook grid cells were commercially fished over 654 vessel days during the 2021 oyster season, and 26 001 tows were recorded in the fishery area, similar to 2020 (27 053 tows). All regions received some fishing. A large portion of the catch (62.5%) and of the tows (64.3%) were recorded from the western region, with 31.5% of all tows and 48.9% of the catch in the western region from five high effort cells (G15, H15, J15, J16, and J17). In decreasing order of effort, the central region received 21.2% of all effort and 22.7% of the catch, the southern region 9.1% of effort and 9.7% of catch, and the eastern region was lowest with 5.4% of effort and 5.1% of catch (see Figure A2.3, Appendix 2).

Grid cell N22 was not sampled in 2022. N22 received only two prospecting tows between 2006 and 2020 and is close to an area that has been constantly fished since 2006. Bycatch sampling in 2021 caught very little bycatch in N22; a total of 21.7 kg of mobile taxa and negligible sessile, erect epibenthic fauna, 75% of which was *O. maculata*.

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 12). 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. The dredges were landed unwashed rather than washed to better describe bycatch taxa present in the dredge and on the seabed.

Table 1: A summary of effort and percentage annual tows for cells selected to be sampled in the February 2022 bycatch survey from those fished during the 2021 Foveaux Strait oyster season (1 March to 31 August). The data are presented by region (Region), by effort category (Effort), and one nautical mile square logbook grid cells (Grid), for all grid cells fished in 2021. Total numbers of dredge tow for all vessels combined (Tows), the total numbers of vessels days fished (Vessel days), and the percentage of the annual tows from the entire fishery (%Effort_F) and from each region (%Effort_R).

Region	Effort	Grid	Tows	Vessel days	%Effort_F	%Effort_R
Central	High	J18	862	22	3.3	15.6
Central	High	K18	898	23	3.5	16.3
Central	High	K19	586	15	2.3	10.6
Central	Moderate	K17	542	12	2.1	9.8
Central	Moderate	L18	440	10	1.7	8.0
Central	Moderate	L20	428	8	1.6	7.8
Central	Low	K20	66	2	0.3	1.2
Central	Low	K21	16	1	0.1	0.3
Central	Low	L21	12	1	0.0	0.2
Central	–	Cells	3 850	94	14.9	69.8
Region	Effort	Grid	Tows	Vessel days	%Effort_F	%Effort_R
Eastern	High	K27	216	6	0.8	15.5
Eastern	High	K28	392	10	1.5	28.1
Eastern	High	L28	276	7	1.1	19.8
Eastern	Moderate	I27	50	1	0.2	3.6
Eastern	Moderate	J28	60	2	0.2	4.3
Eastern	Moderate	K29	62	4	0.2	4.4
Eastern	Low	J26	NA	0	0.0	0.0
Eastern	Low	J27	8	1	0.0	0.6
Eastern	Low	K25	6	1	0.0	0.4
Eastern	–	Cells	1 070	32	4.0	76.7
Region	Effort	Grid	Tows	Vessel days	%Effort_F	%Effort_R
Southern	High	M18	520	14	2.0	22.0
Southern	High	M19	443	10	1.7	18.7
Southern	High	M20	467	11	1.8	19.8
Southern	Moderate	M21	252	6	1.0	10.7
Southern	Moderate	N18	64	3	0.2	2.7
Southern	Moderate	N20	162	5	0.6	6.9
Southern	Low	M15	12	1	0.0	0.5
Southern	Low	M17	2	1	0.0	0.1
Southern	Low	N16	8	1	0.0	0.3
Southern	–	Cells	1 930	52	7.3	81.7
Region	Effort	Grid	Tows	Vessel days	%Effort_F	%Effort_R
Western	High	J15	1 566	35	6.0	9.4
Western	High	J16	1 734	37	6.7	10.4
Western	High	J17	1 526	32	5.9	9.1
Western	Moderate	F12	478	11	1.8	2.9
Western	Moderate	F15	298	9	1.1	1.8
Western	Moderate	G13	278	6	1.1	1.7
Western	Low	F19	8	1	0.0	0.0
Western	Low	G18	NA	0	0.0	0.0
Western	Low	H17	2	1	0.0	0.0
Western	–	Cells	5 890	132	22.6	35.3
All regions	–	All cells	12 740	310	48.8	-

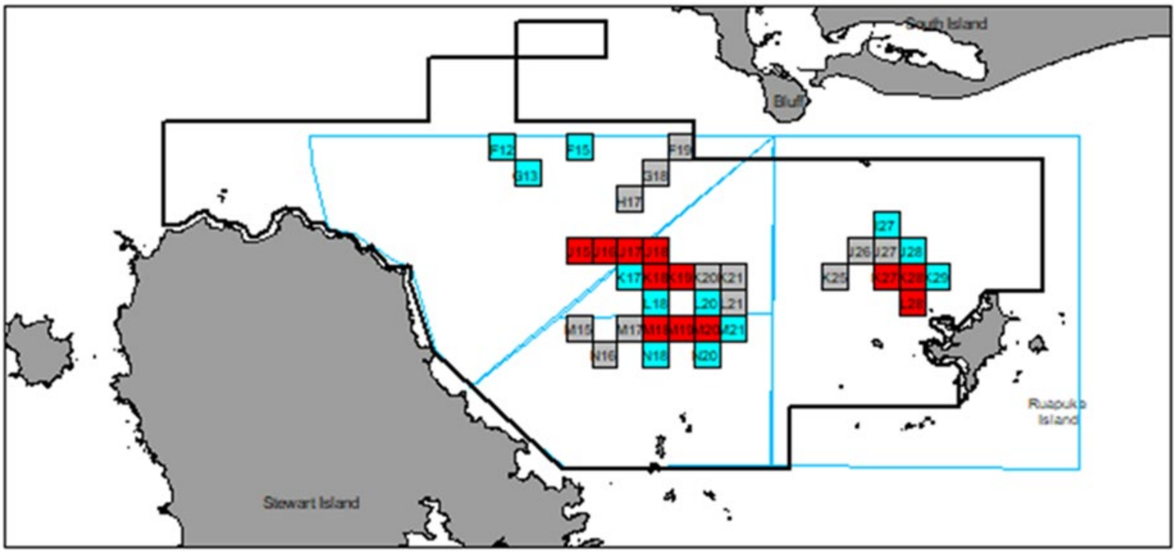

Figure 12: The four fishery regions (West, Central, South, and East) shown as blue lines, the stock assessment survey area shown as grey lines and fishers' logbook grid cells that represent high (red), moderate (cyan), and low (grey) fishing effort for sampling in February 2022. Grid cell N22 was not sampled in 2022.

3.3.1 Estimates of oyster discards

Oyster discards were estimated in two size categories: below MLS; and above MLS. *Nda* is the number of oysters discarded above MLS and *Ndb* is the number 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*, million) by all vessels in 2021:

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

Where:
L is the Fisheries New Zealand reported commercial landings of oysters for the 2021 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 2022:

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

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 2022 oyster survey and (2) counts of live oysters in each of the four size groups from dredge tows sampled during the February 2022 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.

3.3.2 Oyster discards above MLS

Nda, the number of oysters discarded above MLS, is the recruit-sized oysters that are sorted from the catch and returned to sea. Estimates of *Nda* assume that all oysters above commercial size were 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 2021 oyster season, *Nda*, is calculated by:

$$Nda = Cc - L$$

3.3.3 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 (million) below MLS discarded by all vessels in 2021 (*Ndb*):

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

where *Pdb* is given by:

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

Pdb1 is from the survey estimates of population sizes in February 2022.
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. 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).

To maintain sampling efficiency, individual taxa were weighed to a minimum weight of 0.01 kg; however, many samples of taxa were much lighter than 0.01 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
Bryozoans	Bryozoa (Phylum)	COZ

3.5 Estimates of bycatch scaled to fishing effort for the 2021 oyster season

Estimates of bycatch for the 2021 oyster season by region (western, central, southern, and eastern) and by fishing effort strata (high, moderate, and low) were calculated from the mean (Bycatch 1) and median (Bycatch 2) weight of all bycatch species in the February 2022 survey combined, scaled by the mean number of tows recorded from each stratum from fishers' logbooks in 2021. 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

There is no Fisheries New Zealand database for OYU 5 bycatch data, and these data are held as comma separated (CSV) files on NIWA project drives. Several species codes were changed in 2022 to better align with those in the Fisheries New Zealand Marlin database.

- PEL (*Pseudoxyperas elongata*) was changed to **OEL** (*Oxyperas elongatum*),
- STM (*Stichopus mollis*) was changed to **SCC** (*Australostichopus mollis*)
- NTO (previously URC) was changed to **NTM** (*Notomithrax minor*),
- PUP was changed to **TUL** (*Pyura pachydermatina*),
- PPU was changed to **PEP** (*Pentagonaster pulchellus*),
- CMU was changed to **CCM** (*Coscinasterias muricata*),
- CIN was changed to **CIC** (*Crella incrustans*),
- EAU was changed to **TRC** (*Eurynolambrus australis*),

4.1 Summary of sampling in 2022

From the 36 tows sampled in February 2022, total catch was 650 bins (25 323 kg), of which 182 bins (28.0%) of the dredge contents including oysters were subsampled. Total catch in 2022 sampled 18.8% more cases and weighed 6.1% more than in 2021. The total numbers of bins per tow ranged from 5 to 28 in 2022, with a mean number of bins per tow of 18.1. Mean number of bins per tow was 162% higher in 2022 than in 2021. The net weight of individual, subsampled bins ranged from 19 to 68.0 kg in 2022, compared with 2.0 to 68.4 kg in 2021. Mean bin weight, including oysters, was 41.7 kg, heavier than in 2021 (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. More gravel was observed in dredge contents in 2022 than in previous years.

4.2 Non-oyster Bycatch

All bycatch summaries exclude data on live oysters.

4.2.1 Bycatch by category 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 1012.1 kg, 4.0% of the total unsorted catch, representing a considerably lower percentage than in 2021 (25.0%). Bycatch by category is given in Table 3 and the ten highest bycatch species ranked by total weight across the four regions combined are given in Table 4. Non-fish non-QMS species (NFNQMS) accounted for 86.2% of bycatch in 2022, higher than in 2021 (61.4%) (Table 3). All top ten species ranked by weight were NFNQMS and comprised 81.3% of all bycatch (Table 4); two of these species, *Astraea heliotropium* and *Modiolus areolatus*, accounted for 51.1% of all bycatch. All ten species (Table 4) are ubiquitous throughout the Foveaux Strait fishery area.

Table 3: Total weight (kg) of bycatch from all grid cells (n = 36) in February 2022 and percentage of bycatch weight by category: NFNQMS (non-fish, non-QMS, other species not reported), QMS (QMS commercial species), QMSR_COZ (QMS reported bycatch (Bryozoa)), QMSR_ONG (QMS reported bycatch (Porifera)), and NQMSF (non-QMS fish).

Category	Weight (kg)	% Bycatch
NFNQMS	872.27	86.19
QMS	115.03	11.37
QMSR_COZ	19.70	1.95
QMSR_ONG	4.50	0.44
NQMSF	0.58	0.06
	1012.08	100.00

Table 4: The top ten bycatch NFNQMS (non-fish, non-QMS) species by total weight (Wt, kg), as a percentage of all bycatch for all regions combined (% all bycatch), and cumulative percentages (Cum%) in February 2022. Other species are not reported.

Rank	Category	Species	Species code	Wt (kg)	% all bycatch	Cum%
1	NFNQMS	*Astraea heliotropium*	ASH	343.32	33.92	33.92
2	NFNQMS	*Modiolus areolatus*	MAR	173.57	17.15	51.07
3	NFNQMS	*Ophiopsammus maculata*	OMA	116.75	11.54	62.61
4	NFNQMS	*Pseudechinus novaezealandie*	PNO	114.54	11.32	73.92
5	NFNQMS	*Pagurus novizealandiae*	PAG	18.14	1.79	75.72
6	NFNQMS	*Alcithoe arabica*	AAR	14.37	1.42	77.14
7	NFNQMS	*Neothyris compressa*	NCO	13.83	1.37	78.50
8	NFNQMS	*Apatopygus recens*	ARE	11.03	1.09	79.59
9	NFNQMS	*Coscinasterias muricata*	CCM	9.52	0.94	80.53
10	NFNQMS	*Aulacomya atra maoriana*	AMA	7.36	0.73	81.26

Bycatch of QMS species accounted for 11.4% of all bycatch by weight. Kina *Evechinus chloroticus* (SUR) accounted for 10.9% of all bycatch (all regions combined), see Table A3.1 (Appendix 3). Sea cucumbers (*Australostichopus mollis*, SCC) accounted for 0.2% of the bycatch. Few other fish and non-fish QMS species were caught, and their combined weight was negligible.

Bycatch of the two categories bryozoans (QMSR_COZ) and porifera (QMSR_ONG) combined accounted for a further 2.4% of all bycatch in 2022, substantially less than in 2021 (33.4%), and similar to 2020 (4.4%). For details on species within each category, see Table A3.1, Appendix 3). In 2022, the bushy bryozoan *Othoscuticella fusiformis* (OFU) accounted for most of this bycatch.

Median bycatch of all species (excluding oysters) across all tows (n = 36), was 24.0 kg (5th to 95th percentiles, 5.6–60.6 kg). The weights of bycatch per tow in 2022 were generally similar to 2020 and 2021, except for the large catches of *Cinctipora elegans* (CEL) in 2021. Mean weight of individual species ranged from 9.6 kg per tow to < 0.01 kg, with an average across all species of 0.7 kg. There were ten species where average catch per tow was more than 1.0 kg: *A. heliotropium*, *M. areolatus*, *E. chloroticus*, *Pseudechinus novaezealandie*, *Ophiopsammus maculata*, *Chondropsis* spp., *O. fusiformis*, *Alcithoe arabica*, *Argobuccinum pustulosum tumidum*, and *Tucetona laticostata*.

The box plots of catches by bycatch category and fishing effort (Figure 13) 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. Catches of bryozoans QMSR_COZ were from grid cells with the lowest fishing effort (Figure 13).

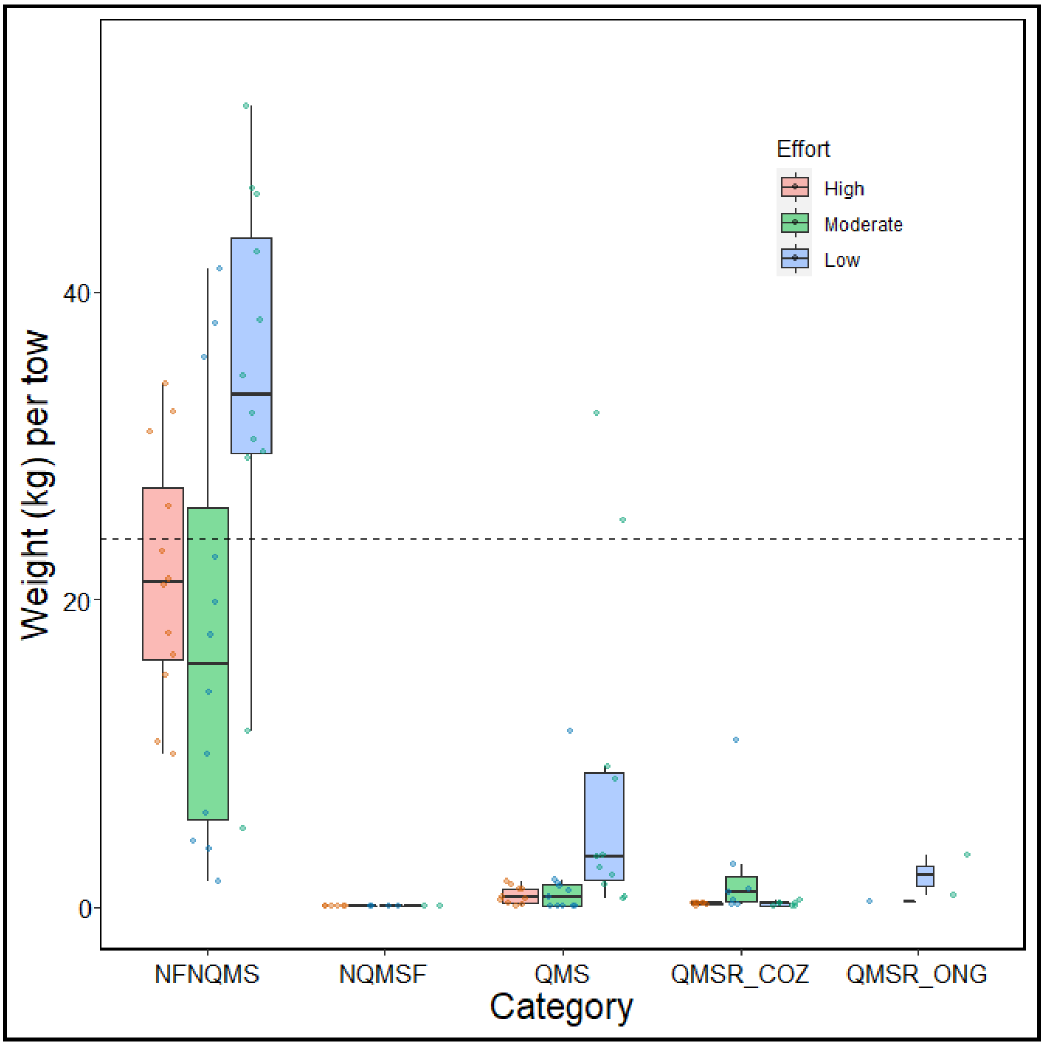

Figure 13: Box plots of the weights of bycatch by category and fishing effort (Effort). Medians shown as solid lines, boxes represent 50th percentiles and whiskers 95th percentiles. The median bycatch weight for all species and categories combined, for all tows is shown as a horizontal black, dashed line (24.0 kg). Outliers for NFNQMS represent large catches of *A. heliotropium* and *M. areolatus*. All species were assigned a minimum weight of 0.01 kg.

4.2.2 Bycatch by region

The top 10 bycatch species in each region (Table 5) accounted for 92.0–97.8% of their respective regional totals in 2022, similar to the percentages in 2021 (91.8–94.5%). Species composition was similar across all four regions (Table 5). The large gastropod *A. heliotropium* (ASH) was the highest bycatch taxon and accounted for 29.6–40.1% of all bycatch in each region. Four other species: *P. novaezealandie* (PNO); *E. chloroticus* (SUR); *M. areolatus* (MAR); and *O. maculata* (OMA) accounted for roughly 50% of the top ten species from each region (Table 5). The only QMS species in the top ten species was SUR (3.2–24.5%), with the highest catches in the eastern region followed by the southern region (Table 5). *Othoscuticella fusiformis* (OFU) was the only bryozoan (QMS_COZ) in the top ten species accounting for 5.0% of bycatch in the western region and 1.7% in the central region. *Chondropsis topsentii* (CTO) was the only sponge (QMS_ONG) in the top ten species accounting for 1.8% in the western region only. All other top ten species were NFNQMS species.

Table 5: The top 10 bycatch species by weight sampled in February 2022 by region as required for IEMRS reporting for the 2021 oyster season. Percentage of total weight by region (Central, Eastern, Southern, and Western) for the top 10 bycatch species (see Table A1.1 Appendix 1 for codes and species identifications). Also included are the total weight of the top 10 species (Top 10 wt. (kg)), total weight of all species by region (Total wt. (kg)), percentage of the regional bycatch (Reg.%), the total bycatch in each region as a percentage of all bycatch from all four regions combined (% all bycatch), and number of taxa (No. taxa) caught.

Species	Central (%)		Species	Eastern (%)		Species	Southern (%)		Species	Western (%)
ASH	34.64		ASH	32.13		ASH	40.10		ASH	29.58
PNO	18.82		SUR	24.48		OMA	14.89		MAR	24.50
MAR	15.50		MAR	16.07		MAR	12.74		OMA	10.79
OMA	13.23		PNO	8.76		PNO	12.70		SUR	8.81
SUR	3.23		OMA	8.27		NCO	2.93		PNO	5.48
NCO	2.27		AAR	2.45		SUR	2.86		OFU	5.02
PAG	1.78		ARE	1.31		AMA	1.96		PAG	3.69
OFU	1.66		PAG	1.04		CCM	1.68		CTO	1.77
CSP	1.41		PRE	0.97		ATU	1.59		AAR	1.40
ARE	1.26		TUL	0.88		ARE	0.95		CCM	0.95
Top 10 wt. (kg)	230.66			294.01			208.39			216.55
Total wt. (kg)	245.95			305.12			225.58			235.44
Reg.%	93.78			96.36			92.38			91.98
% all bycatch	24.30			30.15			22.29			23.26
No. taxa	44			46			42			51

Fewer bycatch taxa were caught in each region in 2022 (Table 5) than in 2021 (47, 47, 61, and 55 bycatch taxa in central, eastern, southern, and western regions, respectively). Regional percentages of total bycatch were more consistent in 2022 (Table 5) than in 2021 (20.6%, 15.7%, 40.3%, and 23.4% bycatch in central, eastern, southern, and western regions, respectively). In 2021 *C. elegans* (CEL) (live and dead branches) accounted for 57.4% of southern bycatch, and *P. pachydermatina* (TUL) accounted for 33.0% of eastern bycatch.

4.2.3 Bycatch by region and effort

Total weight of all bycatch species combined by tow was higher and generally more variable in low effort strata than in moderate and high effort strata (Figure 14). Total weights by each region and fishing effort are given in Tables 6–9. In any given region or effort level, the combined weights of 10 species accounted for more than 93% of bycatch (Tables 6–9). Generally mobile species *A. heliotropium*

(ASH), *O. maculata* (OMA), *E. chloroticus* (SUR), and *P. novaezealandie* (PNO), and the sessile species *M. areolatus* (MAR) accounted for the highest catches across all effort strata and regions.

ASH and OMA are ubiquitous across all regions and effort strata. In 2022, the western region bycatch in the moderate effort stratum was characterised by O. fusiformis (OFU, 26.1%) and Alcithoe arabica (AAR, 7.1%) (Table 6). The central region (Table 7) was characterised by O. maculata (OMA). The southern region (Table 8) was characterised by P. novaezealandie (PNO), and the eastern region (Table 9) by E. chloroticus (SUR). Apart from a relatively small catch of C. topsentii (CTO) in the western low stratum, bycatch of other erect epibenthic species such as C. elegans (CEL) and P. pachydermatina (TUL) were either very small or absent.

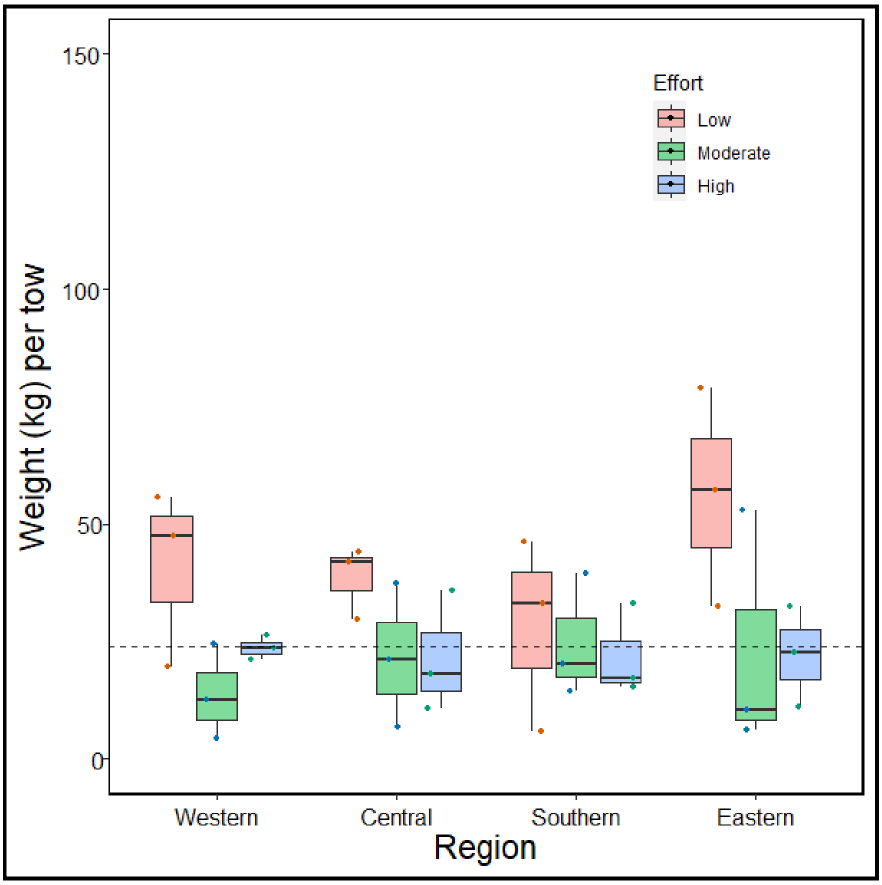

Figure 14: Box plots of the weights of bycatch per tow by region and fishing effort (Effort) in 2022. Medians are shown as solid lines, boxes represent 50th percentiles, and whiskers 95th percentiles. The median bycatch weight for all tows is shown as a horizontal black, dashed line (26.2 kg).

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) in 2022. Weight (kg), percentage each species of total bycatch (percentage), and the weight and percentage of the top 10 ranked species combined (Reg.Eff), by effort stratum. See Table A1.1 Appendix 1 for codes and species identifications.

Western high				Western moderate				Western low		
Species	Weight	Percentage		Species	Weight	Percentage		Species	Weight	Percentage
ASH	38.70	54.48		OFU	10.80	26.08		MAR	52.19	42.43
OMA	12.85	18.09		ASH	7.41	17.90		ASH	23.52	19.12
PNO	6.41	9.03		OMA	6.93	16.74		SUR	18.70	15.21
MAR	4.41	6.20		AAR	2.93	7.08		OMA	5.63	4.57
PAG	2.58	3.63		CCM	2.23	5.40		PNO	4.60	3.74
NCO	1.06	1.50		PNO	1.89	4.56		PAG	4.28	3.48
AMA	0.90	1.26		PAG	1.84	4.45		CTO	4.16	3.38
OHU	0.68	0.95		SUR	1.80	4.35		DZE	1.36	1.10
ARE	0.62	0.88		TLA	1.43	3.45		HDR	1.35	1.09
OFU	0.53	0.75		MAR	1.08	2.62		PRE	1.14	0.93
Reg.Eff	68.74	96.76			38.34	92.62			116.93	95.06

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) in 2022. Weight (kg), percentage each species of total bycatch (percentage), and the weight and percentage of the top 10 ranked species combined (Reg.Eff), by effort stratum. See Table A1.1 Appendix 1 for codes and species identifications.

Central high				Central moderate				Central low		
Species	Weight	Percentage		Species	Weight	Percentage		Species	Weight	Percentage
ASH	23.46	36.14		ASH	31.52	48.31		ASH	30.21	26.09
PNO	12.92	19.90		PNO	10.63	16.29		MAR	28.94	24.99
OMA	11.54	17.77		OMA	8.06	12.35		PNO	22.73	19.63
MAR	5.96	9.18		OFU	4.00	6.13		OMA	12.94	11.17
NCO	1.99	3.06		MAR	3.21	4.92		SUR	4.88	4.22
SUR	1.87	2.88		NCO	1.32	2.02		AAR	2.96	2.55
ARE	1.50	2.32		SUR	1.19	1.82		PAG	2.44	2.11
CSP	1.06	1.64		PAG	1.15	1.76		NCO	2.28	1.97
CCM	0.95	1.47		ARE	0.84	1.29		CSP	1.64	1.42
PAG	0.79	1.22		CSP	0.75	1.15		CCM	1.13	0.98
Reg.Eff	62.04	95.58			62.67	96.06			110.15	95.12

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) in 2022. Weight (kg), percentage each species of total bycatch (percentage), and the weight and percentage of the top 10 ranked species combined (Reg.Eff), by effort stratum. See Table A1.1 Appendix 1 for codes and species identifications.

Southern high				Southern moderate				Southern low		
Species	Weight	Percentage		Species	Weight	Percentage		Species	Weight	Percentage
ASH	25.57	38.77		ASH	26.71	35.94		ASH	38.17	44.74
OMA	13.72	20.81		PNO	13.52	18.19		PNO	8.66	10.15
MAR	12.89	19.54		OMA	11.42	15.37		OMA	8.45	9.90
PNO	6.47	9.81		MAR	10.09	13.57		MAR	5.77	6.77
SUR	1.33	2.01		SUR	1.59	2.14		NCO	5.76	6.75
ARE	0.79	1.19		CCM	1.47	1.98		ATU	3.58	4.19
TNE	0.74	1.12		SCC	1.35	1.82		SUR	3.53	4.13
AAR	0.65	0.98		ARE	1.10	1.48		AMA	3.50	4.11
AMA	0.61	0.93		TNE	0.90	1.21		SCA	1.86	2.18
CCM	0.53	0.81		PAG	0.88	1.18		CCM	1.78	2.08
Reg.Eff	63.3	95.96			69.03	92.89			81.06	95.00

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) in 2022. Weight (kg), percentage each species of total bycatch (percentage), and the weight and percentage of the top 10 ranked species combined (Reg.Eff), by effort stratum. See Table A1.1 Appendix 1 for codes and species identifications.

Eastern high				Eastern moderate				Eastern low		
Species	Weight	Percentage		Species	Weight	Percentage		Species	Weight	Percentage
ASH	48.56	73.10		ASH	23.11	33.06		SUR	58.71	34.78
OMA	4.73	7.11		SUR	12.07	17.26		MAR	36.25	21.48
SUR	3.93	5.91		MAR	11.25	16.09		ASH	26.38	15.63
MAR	1.54	2.31		PNO	7.63	10.91		PNO	17.78	10.54
ARE	1.47	2.21		OMA	7.18	10.27		OMA	13.32	7.89
PNO	1.31	1.97		ARE	1.76	2.52		AAR	5.76	3.42
PAG	1.04	1.57		AAR	1.00	1.43		TUL	2.04	1.21
AAR	0.71	1.07		CCM	0.99	1.41		PRE	1.94	1.15
GMO	0.50	0.75		PAG	0.84	1.20		PAG	1.28	0.76
PRE	0.41	0.62		PRE	0.62	0.89		MGR	0.84	0.50
Reg.Eff	64.2	96.63			66.45	95.04			164.3	97.34

4.2.4 Estimated catch by bycatch category and region

Across all regions, total bycatch in high effort strata accounted for 26.5%, moderate effort strata 24.8%, and low effort strata 48.7% of all bycatch (Table 10). QMS and QMS reportable bycatch species (QMSR_COZ and QMSR_ONG) accounted for a relatively small percentage of bycatch (13.8%) in 2022 (Table 10), most of which was SUR in the eastern region where it accounted for 7.5%. Other QMS and QMS reportable bycatch species (QMSR_COZ and QMSR_ONG) were negligible. Non-fish, non-QMS species (NFNQMS) accounted for most of the bycatch in all regions and effort strata combined (Table 10). NFNQMS also accounted for most of the bycatch across individual regions. Non QMS fish bycatch (NQMSF) was negligible.

Table 10: Total weight (kg) of each bycatch species category (NFNQMS, NQMSF, QMS, QMSR_COZ, QMSR_ONG), by region and fishing effort (High, Moderate, and Low). Percentage of each bycatch category as a percentage of all three effort levels and the combined weight of each bycatch category (All eff. (wt)) by region and fishing effort. The percentage of each bycatch to the total weight of bycatch from all four regions (Region (%)). Also included is a summary across all four regions (All Regions). (Continued on next page)

Category	High (wt)	High (%)	Moderate (wt)	Moderate (%)	Low (wt)	Low (%)	All eff. (wt)	Region (%)
Central Region								
NFNQMS	62.57	26.97	59.46	25.63	109.96	47.40	231.99	22.92
NQMSF	0.00	0.00	0.05	100.00	0.00	0.00	0.05	0.00
QMS	2.02	23.11	1.23	14.10	5.48	62.78	8.72	0.86
QMSR_COZ	0.32	6.21	4.50	86.74	0.37	7.05	5.19	0.51
QMSR_ONG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	64.91	26.39	65.24	26.53	115.80	47.08	245.95	
Eastern Region								
NFNQMS	62.20	27.14	57.60	25.14	109.33	47.71	229.13	22.64
NQMSF	0.16	45.76	0.09	25.99	0.10	28.25	0.35	0.03
QMS	4.08	5.39	12.21	16.14	59.35	78.47	75.64	7.47
QMSR_COZ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
QMSR_ONG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	66.44	21.77	69.91	22.91	168.78	55.31	305.12	
Southern Region								
NFNQMS	63.70	29.72	69.61	32.48	81.01	37.80	214.32	21.18
NQMSF	0.07	53.85	0.06	46.15		0.00	0.13	0.01
QMS	1.45	17.20	3.00	35.63	3.97	47.17	8.41	0.83
QMSR_COZ	0.74	31.23	1.30	54.71	0.33	14.06	2.38	0.23
QMSR_ONG	0.00	0.00	0.34	100.00	0.00	0.00	0.34	0.03
Total	65.96	29.24	74.31	32.94	85.31	37.82	225.58	

Table 10: Continued.

Category	High (wt)	High (%)	Moderate (wt)	Moderate (%)	Low (wt)	Low (%)	All eff. (wt)	Region (%)
Western Region								
NFNQMS	70.12	35.63	28.69	14.57	98.02	49.80	196.83	19.45
NQMSF	0.05	100.00		0.00		0.00	0.05	0.00
QMS	0.28	1.25	1.89	8.50	20.09	90.25	22.26	2.20
QMSR_COZ	0.58	4.78	10.83	89.22	0.73	6.00	12.14	1.20
QMSR_ONG	0.00	0.00	0.00	0.00	4.16	100.00	4.16	0.41
Total	71.03	30.17	41.41	17.59	123.00	52.24	235.44	
All Regions								
NFNQMS	258.59	29.65	215.36	24.69	398.32	45.66	872.27	86.19
NQMSF	0.28	48.29	0.20	34.59	0.10	17.12	0.58	0.06
QMS	7.82	6.80	18.33	15.93	88.88	77.27	115.03	11.37
QMSR_COZ	1.64	8.34	16.63	84.41	1.43	7.25	19.70	1.95
QMSR_ONG	0.00	0.00	0.34	7.52	4.16	92.48	4.50	0.44
Total	268.34	26.51	250.86	24.79	492.89	48.70	1 012.08	

4.2.5 Estimates of fishery-scale bycatch in the sampled cells for the 2021 oyster season

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 2021 oyster season (Figure 15 and Table 11). High fishing effort strata accounted for 76.3% of annual bycatch from the fishery, moderate effort for 21.6%, and low effort strata for 2.1% in 2021, compared with 93.0%, 6.6%, and 0.16%, respectively in 2020. The western region had the highest percentage of scaled bycatch (45.7%), followed in order of rank by the central region (30.0%), the southern region (15.5%), and the eastern region (8.7%). Ranks were the same as for 2020: 33.2%, 28.7%, 22.8%, and 14.2% for western, central, southern, and eastern regions, respectively. 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 2021 are given in Table A3.2 (Appendix 3).

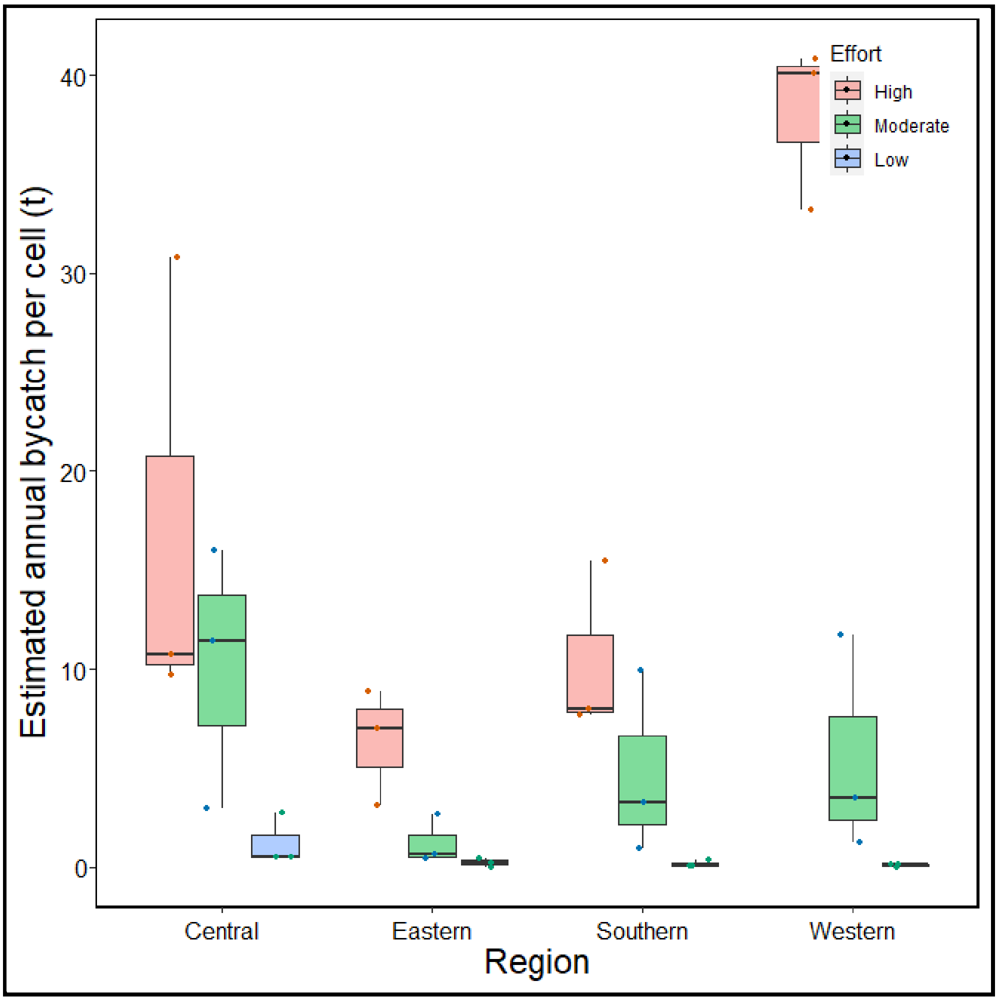

Figure 15: Boxplots of bycatch weight (t) scaled by the number of tows in each grid cell during the 2021 oyster season and shown by region and fishing effort (Effort). Medians are shown as solid lines, boxes represent 50th percentiles, and whiskers 95th percentiles.

Table 11: Weight of 2021 oyster season bycatch, estimated by region (central, eastern, southern, and western) and by fishing effort (Region and fish effort). The average number of tows in each stratum (Mean no. tows), average weight for all species combined (Mean Weight, kg), median weight (Median Weight, kg)), 5th and 95th percentiles (Weight 5th % and Weight 95th %, respectively). Bycatch 1 (t) is calculated scaling average weight by number of tows, and Bycatch 2 by the median weight. % All bycatch gives the percentage of each region and stratum to the estimated total catch from all 36 grid cells.

Region and fish effort	Mean no. tows	Mean weight	Median weight	Weight 5th %	Weight 95th %	Bycatch 1 (t)	Bycatch 2 (t)	% All bycatch
Central Region								
High	782.0	21.6	18.3	11.6	34.0	16.9	14.3	17.9
Moderate	470.0	21.7	21.1	8.1	35.8	10.2	9.9	10.8
Low	31.3	38.6	41.9	31.0	43.9	1.2	1.3	1.3
Eastern Region								
High	294.7	22.1	22.6	12.3	31.6	6.5	6.7	6.9
Moderate	57.3	23.3	10.6	6.7	48.8	1.3	0.6	1.4
Low	7.0	56.3	57.4	35.0	76.7	0.4	0.4	0.4
Southern Region								
High	476.7	22.0	17.4	15.6	31.6	10.5	8.3	11.1
Moderate	159.3	24.8	20.4	15.1	37.5	3.9	3.3	4.2
Low	7.3	28.4	33.2	8.6	45.0	0.2	0.2	0.2
Western Region								
High	1608.7	23.7	23.6	21.5	26.0	38.1	37.9	40.4
Moderate	351.3	13.8	12.6	5.1	23.3	4.8	4.4	5.1
Low	5.0	41.0	47.3	22.5	55.0	0.2	0.2	0.2

4.3 Oyster discards

In February 2022, the combined survey estimate of mean population size for all four size groups of oysters in the Bonamia survey area was 2044.8 million oysters, a decrease of 14.1% from 2021 (2379.6 million oysters), and an increase of 10.6% from 2020 (1847.6 million oysters). The 2022 population size comprised 557.9 million recruits (in this case all oysters above and including recruit size, i.e., commercial- and recruit-sized combined), 370.3 million pre-recruits, and 1116.6 million small oysters (Michael et al. 2023). The reported commercial landings of oysters for the 2021 oyster season (L) were 7.65 million oysters (Fisheries New Zealand extract rep log 14644, 18 October 2022).

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 15.1 million oysters, similar to the 2021 estimate (16.1 million), 2.7% of the recruited population in the Bonamia survey area in 2022 (2.0% in 2021 and 3.3% in 2020), where L = 7.65 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 2022, and $PL2$, the mean proportion of oysters above MLS that were of commercial size from bycatch sampling, were the same proportion (0.481).

4.3.1 Oyster discards above minimum legal size

The estimate of oysters above MLS discarded (Nda) was 7.5 million, or 49.4% of all oysters caught above MLS. Nda represented 1.3% of the recruited population in the Bonamia survey area in 2022, more than in 2021 (1.0%) and fewer than in 2020 (1.5%).

4.3.2 Oyster discards below minimum legal size

Pdb1 was estimated to be 0.727 (1486.9 million oysters below MLS out of 2044.8 million oysters of all sizes) of the population size of all four of the size groups of oysters in the Bonamia survey area in February 2022 (Michael et al. 2023.

Pdb2, the mean proportion of oysters below MSL, from the 36 bycatch tows in February 2022 was 0.713.

Pdb2 was used to estimate the number of oysters below MLS that were discarded (*Ndb*) in the 2021 oyster season, which was 55.5 million. The percentage of discards below MLS of the population of all sized oysters in the Bonamia survey area was 2.7% in 2022 (2.0% in 2021 and 3.3% in 2020).

5. DISCUSSION

A survey in February 2022 described and quantified the bycatch from dredge catches to estimate the annual bycatch from sampled cells for the 2021 oyster season. There is uncertainty around annual estimates of bycatch from the fishery that are scaled up from these data. Bycatch weights by grid cell scaled by the number of tows recorded for the 2021 oyster season, and then extrapolated to the whole fishery, are likely to have high uncertainty. These uncertainties and the difficulties in comparing bycatch from the four fishery regions across years are discussed by Michael (2022b). A key uncertainty is whether the catch from each site sampled is representative of the areas fished within grid cells. The bycatch of small-bodied taxa may also have been overestimated by the 0.01 kg minimum weight.

The one square nautical mile grid cells represent a relatively large area. Commercial dredging mostly occurs in a small portion of any grid cell. The single randomly allocated tows within grid cells have a high chance of not sampling the area fished in the last oyster season, even in cells with high fishing effort. The risk of this mismatch increases substantially for low effort cells that may have only received one or two fishing events. Two methods of reducing this uncertainty are to:

1. Clearly delimit the proportion of each grid cell fished using 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. These data could accurately delineate the elliptical tows within the grid cells fished.
2. To partition each grid cell to be sampled e.g., in to four 0.5 nautical mile squares. This would greatly increase sampling effort; however, bycatch sampling could be confined to the region with the highest bycatch, e.g., scaled, annual bycatch from the western region in 2022 accounted for 45.7% of bycatch from the fishery in 2021.

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 on benthic habitats.

5.1 Oyster discards and bycatch

The February 2022 oyster survey found population size estimates for commercial and recruit-sized oysters both decreased by 30.4%, and pre-recruits by 24.0%. These decreases between 2021 and 2022 could not be accounted for by fishery landings in 2021, and the estimated mortality of oysters that died between surveys. There may have been a reduction of dredge efficiency (catchability of oysters) in 2022 due to changes in the seabed. The unusually high volumes of gravel in most dredge tows and seawater temperature anomalies since mid-January 2022 (that suggest different weather systems) may have mobilised bottom sediments throughout Foveaux Strait. At the beginning of the oyster season in March 2022, skippers reported more gravel in catches and lower than expected catch rates. Bycatch sampled in February 2022 was characterised by heavier sample bin weights and more gravel.

5.1.1 Oyster discards

Incidental mortality of discards is expected to be low, less than 2% (Cranfield et al. 1997). 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 were increasing rapidly until 2021 and the reduction in commercial, recruit, and pre-recruit-sized oysters between 2021 and 2022 remains unexplained; however, population estimates of small oysters were similar between 2021 and 2022.

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 were 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. Oyster meat quality was mostly low across the fishery area suggesting higher levels of discards above MLS. Estimated numbers of oysters above MLS discarded by the OYU 5 fishery during the 2021 season were 7.5 million, or 49.4% of all oysters caught above MLS, and represented 1.3% of the recruited population in the Bonamia survey area in February 2022, more than in 2021 (1.0%) and fewer than in 2020 (1.5%).

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 the Bonamia survey area (72.7% in 2022) were similar to those for 2021 and 2020 (66.4% and 71.3%, respectively). The number of oysters below MLS discarded in the 2021 oyster season was 55.5 million, compared with 48.1 million in the 2020 oyster season. 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 was 2.7% in 2021 (2.0% in 2020 and 3.3% in 2019). 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).

5.1.2 Bycatch

Bycatch sampling data describe the benthic taxa caught by commercial oyster dredges during the previous oyster season and are used to estimate bycatch weights of the top ten species from selected logbook reporting grid cells. Mean bycatch weights by high, moderate, and low fishing effort within each region are scaled by the mean number of dredge tows in each effort stratum to estimate annual bycatch. Whilst fishing effort between the 2020 and 2021 oyster seasons was similar, with 26 001 tows (654 vessel days) in 2021 and 27 053 tows in 2020, the distribution of fishing effort varied. Interannual comparisons of bycatch from the fishery and by region are likely to be driven by the differences in the distributions of fishing effort from year to year and, to some extent, from the survey variation from random tows within sampled grid cells.

In 2022, all the top ten bycatch species ranked by weight (86.2% of bycatch) were non-fish non-QMS species that are ubiquitous throughout the fishery area. Two of these species *Astraea heliotropium* and *Modiolus areolatus* accounted for 51.1% of all bycatch. QMS species accounted for 11.4% of all bycatch by weight: kina (*Evechinus chloroticus*, SUR) accounted for 10.9%; and sea cucumbers (*Australostichopus mollis*, SCC) accounted for 0.2%. Bycatch of bryozoans and porifera combined accounted for a further 2.4% of all bycatch; the bushy bryozoan *Othoscuticella fusiformis* (OFU) accounted for most of this bycatch. In 2022, bryozoan and porifera bycatch was substantially less than in 2021 (33.4%), and similar to 2020 (4.4%).

These bycatch data are consistent with bycatch data recorded in fishers' logbooks which reflect relatively simple benthic habitats of sand, gravel, and shell with relatively few patches of erect epibenthic fauna such as bryozoan and porifera in fished areas.

5.2 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., *C. elegans*, *P. pachydermatina*, *Chondropsis* spp., *C. incrustans*, and *M. 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.

6. POTENTIAL RESEARCH

6.1 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 2021 survey design and methods, 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 0.01 kg and counts recorded for each non-colonial species.

The frequency of surveys could be reviewed. A bycatch survey may not need to be repeated every year, but the most appropriate number of years between surveys needs to be evaluated after the results of several bycatch surveys are compared. Bycatch surveys have been undertaken in 2019, 2020, 2021, and 2022.

6.2 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 cage 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.

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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*	**OEL**	*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*	**TUL**	*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*	**NTM**	*Notomithrax* sp.	**SMO**	*Sclerasterias mollis*
CAO	*Cardita aoteana*	**NUD**	*Nudibranchs*	**SCC**	*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*
CIC	*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

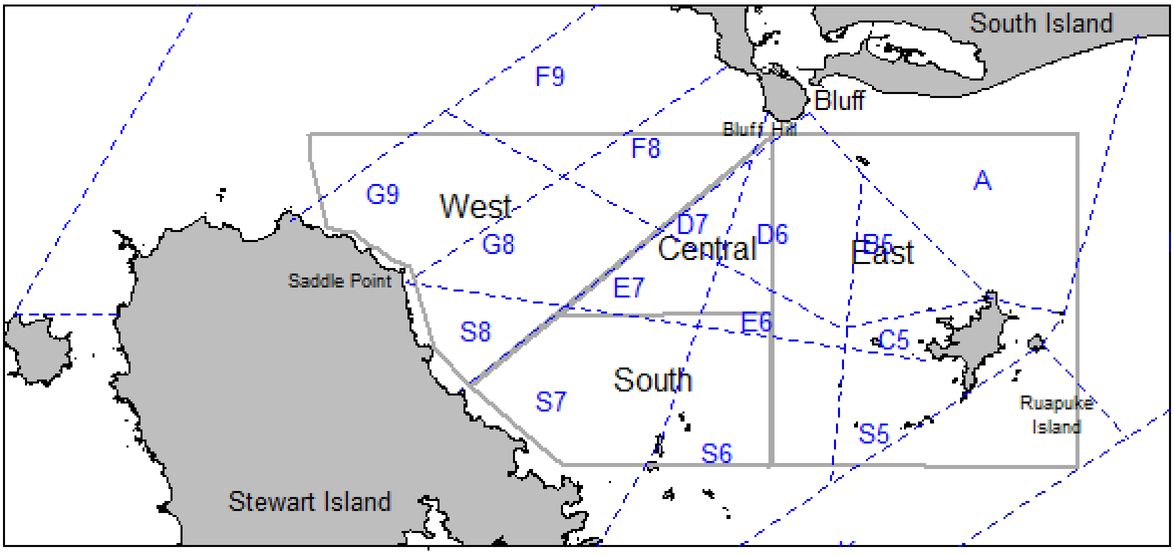

Figure A2.1: The OYU 5 fishery area with the four commercial fishery regions (West, Central, South, East shown as grey lines and labelled in black text) and the Foveaux Strait Oyster statistical reporting areas (dashed blue lines labelled in blue text).

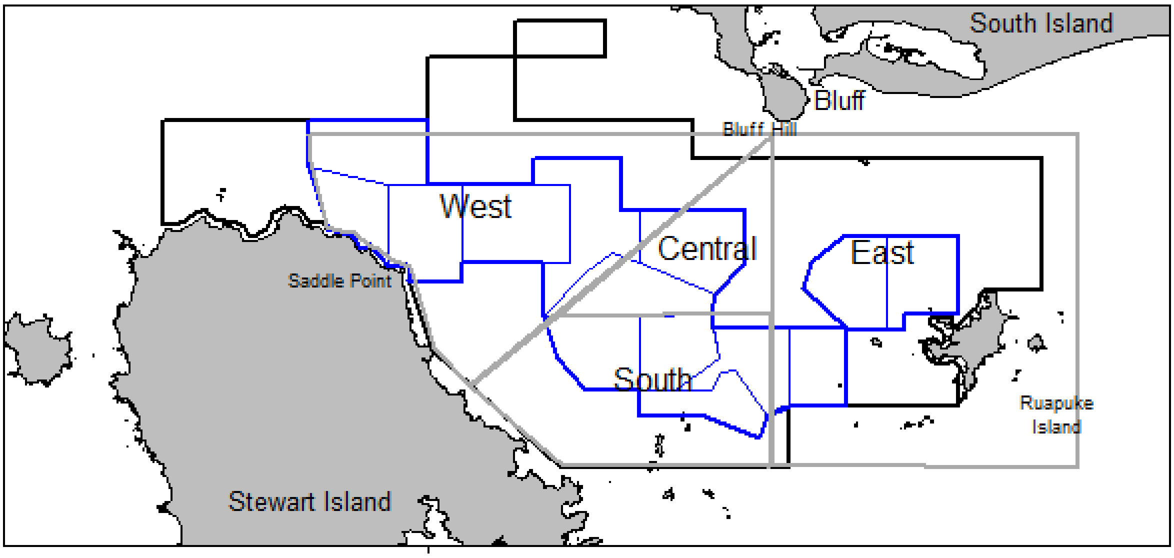

Figure A2.2: The OYU 5, 2007 stock assessment survey area (black lines), the boundary of the Bonamia survey area (blue lines) with the four commercial fishery regions (West, Central, South, East shown as grey lines and labelled in black text).

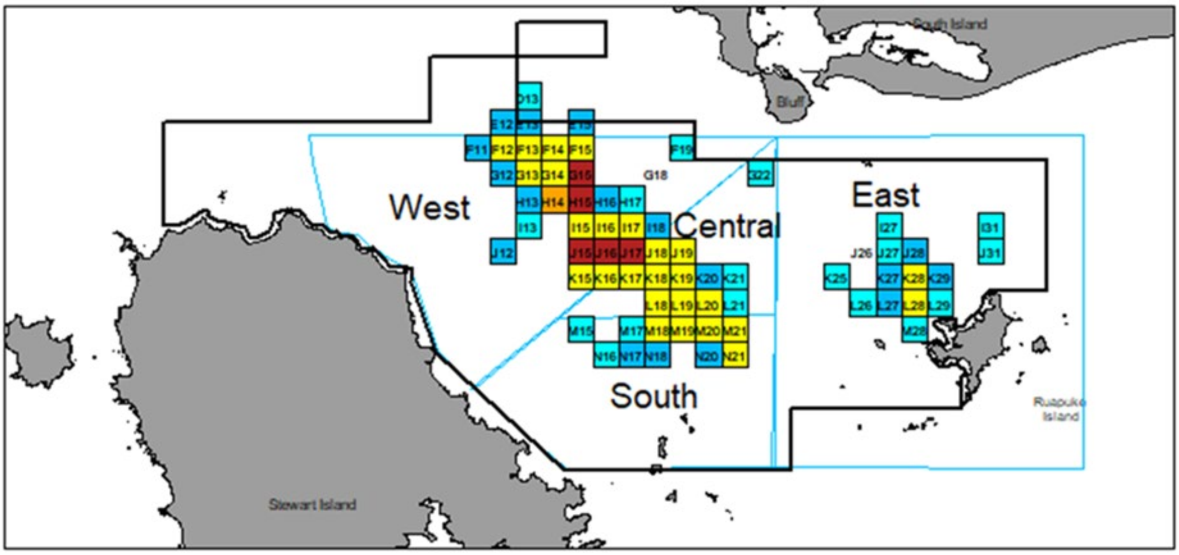

Figure A2.3: The distribution of total tows for the 2021 Foveaux Strait oyster season. Grid cells are colour coded cyan for 1–50 tows, sky blue for 51–250 tows, yellow for 251–1000 tows, orange for 1001–1500 tows, and red for over 1500 tows. Grid cells where no fishing took place are blank. The four fishery regions (West, Central, South, and East) are delimited by blue lines. The boundary of the 2007 stock assessment survey area is shown as a heavy, black outer line.

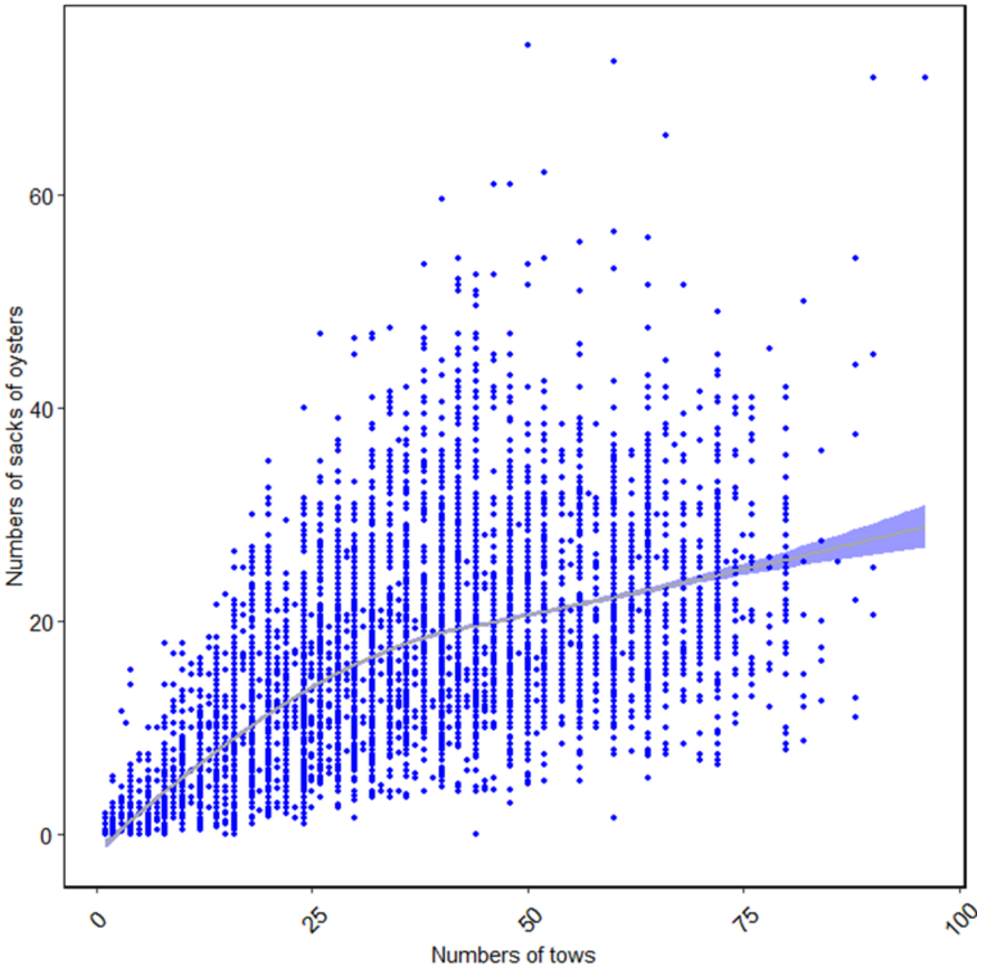

Figure A2.4: Scatter plot of number of dredge tows per fishers' logbook grid cell per day against the number of sacks of oysters (*Ostrea chilensis*). Correlation described by loess smoother ± 1SD.

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

Table A3.1: Total weight (kg) from the February 2022 bycatch sampling by category, 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), QMS (QMS commercial species), QMSR_COZ (QMS reported bycatch (Bryozoa)), QMSR_ONG (QMS reported bycatch (Porifera)) and NQMSF (fish, non-QMS) bycatch (see table 2 Fisheries New Zealand 2018).

Category	Class	Species	Weight (kg)	% Category	% Bycatch
NFNQMS	Gastropoda	ASH	343.316	39.36	33.92
NFNQMS	Bivalvia	MAR	173.570	19.90	17.15
NFNQMS	Ophiuroidea	OMA	116.750	13.38	11.54
NFNQMS	Echinoidea	PNO	114.542	13.13	11.32
NFNQMS	Malacostraca	PAG	18.140	2.08	1.79
NFNQMS	Gastropoda	AAR	14.374	1.65	1.42
NFNQMS	Rhynchonellata	NCO	13.830	1.59	1.37
NFNQMS	Echinoidea	ARE	11.030	1.26	1.09
NFNQMS	Asteroidea	CCM	9.520	1.09	0.94
NFNQMS	Bivalvia	AMA	7.364	0.84	0.73
NFNQMS	Asteroidea	PRE	4.814	0.55	0.48
NFNQMS	Asteroidea	PEP	4.738	0.54	0.47
NFNQMS	Gastropoda	ATU	4.594	0.53	0.45
NFNQMS	Ascidiacea	TUL	4.206	0.48	0.42
NFNQMS	Cephalopoda	OHU	4.028	0.46	0.40
NFNQMS	Gastropoda	CSP	3.458	0.40	0.34
NFNQMS	Polyplacophora	RCA	2.752	0.32	0.27
NFNQMS	Bivalvia	GMO	2.226	0.26	0.22
NFNQMS	Bivalvia	TLA	2.130	0.24	0.21
NFNQMS	Bivalvia	SCA	2.006	0.23	0.20
NFNQMS	Gastropoda	CAL	1.980	0.23	0.20
NFNQMS	Bivalvia	MCO	1.848	0.21	0.18
NFNQMS	Hydrozoa	HDR	1.372	0.16	0.14
NFNQMS	Gastropoda	MGR	1.016	0.12	0.10
NFNQMS	Bivalvia	MIM	1.014	0.12	0.10
NFNQMS	Bivalvia	VPU	0.886	0.10	0.09
NFNQMS	Malacostraca	TRC	0.696	0.08	0.07
NFNQMS	Asteroidea	AIN	0.692	0.08	0.07
NFNQMS	Bivalvia	OEL	0.560	0.06	0.06
NFNQMS	Ophiuroidea	ALP	0.548	0.06	0.05
NFNQMS	Polyplacophora	ENO	0.534	0.06	0.05
NFNQMS	Rhynchonellata	NLE	0.502	0.06	0.05
NFNQMS	Bivalvia	TAL	0.492	0.06	0.05
NFNQMS	Malacostraca	NEC	0.338	0.04	0.03
NFNQMS	Polyplacophora	CPO	0.332	0.04	0.03
NFNQMS	Echinoidea	PHU	0.286	0.03	0.03
NFNQMS	Malacostraca	NTM	0.282	0.03	0.03

Table A3.1: Continued.

Category	Class	Species	Weight (kg)	% Category	% Bycatch
NFNQMS	Malacostraca	MNO	0.228	0.03	0.02
NFNQMS	Bivalvia	BNO	0.210	0.02	0.02
NFNQMS	Echinoidea	PAL	0.192	0.02	0.02
NFNQMS	Bivalvia	YME	0.158	0.02	0.02
NFNQMS	Gastropoda	SIN	0.154	0.02	0.02
NFNQMS	Bivalvia	TSP	0.122	0.01	0.01
NFNQMS	Gastropoda	NUD	0.122	0.01	0.01
NFNQMS	Asteroidea	AMI	0.118	0.01	0.01
NFNQMS	Hexanauplia	SLU	0.096	0.01	0.01
NFNQMS	Hydrozoa	NEL	0.050	0.01	0.00
NFNQMS	Sipunculacea	SIP	0.030	<0.01	<0.01
NFNQMS	Bivalvia	SNS	0.026	<0.01	<0.01
NFNQMS total			872.272	100.00	86.19
Category	**Class**	**Species**	**Weight (kg)**	**% Category**	**% Bycatch**
QMS	Echinoidea	SUR	109.824	95.48	10.85
QMS	Holothuroidea	SCC	1.992	1.73	0.20
QMS	Bivalvia	DZE	1.398	1.22	0.14
QMS	Bivalvia	GLM	0.708	0.62	0.07
QMS	Actinopteri	BCO	0.546	0.47	0.05
QMS	Actinopteri	LSO	0.440	0.38	0.04
QMS	Cephalopoda	OCT	0.078	0.07	0.01
QMS	Actinopteri	LEA	0.042	0.04	<0.01
QMS total			115.028	100.00	11.37
Category	**Class**	**Species**	**Weight (kg)**	**% Category**	**% Bycatch**
QMSR_COZ	Gymnolaemata	OFU	15.976	81.09	1.58
QMSR_COZ	Gymnolaemata	TNE	2.860	14.52	0.28
QMSR_COZ	Gymnolaemata	CEL	0.480	2.44	0.05
QMSR_COZ	Gymnolaemata	CAG	0.386	1.96	0.04
QMSR_COZ total			19.702	100.00	1.95
Category	**Class**	**Species**	**Weight (kg)**	**% Category**	**% Bycatch**
QMSR_ONG	Demospongiae	CTO	4.496	100.00	0.44
QMSR_ONG total			4.496	100.00	0.44
Category	**Class**	**Species**	**Weight (kg)**	**% Category**	**% Bycatch**
NQMSF	Actinopterygii	TEW	0.392	67.12	0.04
NQMSF	Actinopterygii	PIP	0.112	19.18	0.01
NQMSF	Actinopteri	BUL	0.08	13.70	0.01
NQMSF total			0.584	100.00	0.06

Table A3.1: Mean bycatch weight per tow (BYC wt, in kg) for all species combined by Region, Fishing effort (Effort) and logbook grid cell (Grid) from the February 2022 bycatch sampling. For each logbook grid cell, the number of tows (Tows) from the fishers' 2021 oyster season (1 March to 31 August) logbook data, the number of vessel days (Vessel days), the percentage of all tows during the 2021 oyster season across the fishery (%Effort F) and from each region (%Effort R), numbers of sacks landed from each stratum in 2021 (Catch (s)), the percentage of all commercial catch across the fishery (%Catch F) and from each region (%Catch R). Estimates of total bycatch (BYC, t) from each grid cell for the 2021 oyster season estimated by scaling up the total bycatch per tow by the number of tows in each grid cell is also provided.

Region	Effort	Grid	Tows	Vessel days	%Effort F	%Effort R	Catch (s)	%Catch F	%Catch R	BYC wt	BYC (t)
Central	High	J18	862	22	3.32	15.62	330	3.51	15.45	35.78	30.85
Central	High	K18	898	23	3.45	16.27	336	3.58	15.73	10.84	9.73
Central	High	K19	586	15	2.25	10.62	236	2.51	11.05	18.29	10.72
Central	Moderate	K17	542	12	2.08	9.82	186	1.98	8.71	21.08	11.43
Central	Moderate	L18	440	10	1.69	7.97	186	1.98	8.71	6.71	2.95
Central	Moderate	L20	428	8	1.65	7.76	186.5	1.99	8.73	37.45	16.03
Central	Low	K20	66	2	0.25	1.20	32.5	0.35	1.52	41.88	2.76
Central	Low	K21	16	1	0.06	0.29	5	0.05	0.23	29.76	0.48
Central	Low	L21	12	1	0.05	0.22	4	0.04	0.19	44.16	0.53
Central total	-	Cells	3 850	94	14.81	69.77	1502	15.99	70.32	245.95	946.91
Region	**Effort**	**Grid**	**Tows**	**Vessel days**	**%Effort F**	**%Effort R**	**Catch (s)**	**%Catch F**	**%Catch R**	**BYC wt**	**BYC (t)**
Eastern	High	K27	216	6	0.83	15.49	80.5	0.86	16.97	32.59	7.04
Eastern	High	K28	392	10	1.51	28.12	126.5	1.35	26.66	22.64	8.87
Eastern	High	L28	276	7	1.06	19.80	131	1.39	27.61	11.21	3.09
Eastern	Moderate	I27	50	1	0.19	3.59	11.5	0.12	2.42	53.07	2.65
Eastern	Moderate	J28	60	2	0.23	4.30	16.5	0.18	3.48	10.60	0.64
Eastern	Moderate	K29	62	4	0.24	4.45	20	0.21	4.21	6.24	0.39
Eastern	Low	J26	0	0	0.00	0.00	0	0.00	0.00	78.88	0.00
Eastern	Low	J27	8	1	0.03	0.57	2	0.02	0.42	57.36	0.46
Eastern	Low	K25	6	1	0.02	0.43	2	0.02	0.42	32.54	0.20
Eastern total	-	Cells	1 070	32	4.12	76.76	390	4.15	82.19	305.12	326.48

Table A3.2: Continued.

Region	Effort	Grid	Tows	Vessel days	%Effort F	%Effort R	Catch (s)	%Catch F	%Catch R	BYC wt	BYC (t)
Southern	High	M18	520	14	2.00	22.00	199	2.12	21.90	15.43	8.02
Southern	High	M19	443	10	1.70	18.74	193	2.06	21.24	17.38	7.70
Southern	High	M20	467	11	1.80	19.75	181	1.93	19.92	33.16	15.48
Southern	Moderate	M21	252	6	0.97	10.66	107.5	1.14	11.83	39.45	9.94
Southern	Moderate	N18	64	3	0.25	2.71	17.5	0.19	1.93	14.46	0.93
Southern	Moderate	N20	162	5	0.62	6.85	51.5	0.55	5.67	20.40	3.30
Southern	Low	M15	12	1	0.05	0.51	2.5	0.03	0.28	5.84	0.07
Southern	Low	M17	2	1	0.01	0.08	0.5	0.01	0.06	33.18	0.07
Southern	Low	N16	8	1	0.03	0.34	1	0.01	0.11	46.29	0.37
Southern total	-	Cells	1 930	52	7.42	81.64	753.5	8.02	82.94	225.58	435.36
Region	**Effort**	**Grid**	**Tows**	**Vessel days**	**%Effort F**	**%Effort R**	**Catch (s)**	**%Catch F**	**%Catch R**	**BYC wt**	**BYC (t)**
Western	High	J15	1 566	35	6.02	9.36	510.5	5.44	8.69	21.22	33.24
Western	High	J16	1 734	37	6.67	10.37	554	5.90	9.43	23.55	40.84
Western	High	J17	1 526	32	5.87	9.12	517	5.50	8.80	26.26	40.07
Western	Moderate	F12	478	11	1.84	2.86	150.5	1.60	2.56	24.51	11.72
Western	Moderate	F15	298	9	1.15	1.78	115	1.22	1.96	4.28	1.28
Western	Moderate	G13	278	6	1.07	1.66	88.5	0.94	1.51	12.61	3.51
Western	Low	F19	8	1	0.03	0.05	2	0.02	0.03	19.79	0.16
Western	Low	G18	0	0	0.00	0.00	0	0.00	0.00	47.34	0.00
Western	Low	H17	2	1	0.01	0.01	1	0.01	0.02	55.87	0.11
Western total	-	Cells	5 890	132	22.65	35.22	1 938.5	20.64	33.01	235.44	1 386.73
All regions	**-**	**All cells**	**12 740**	**310**	**49.00**	**-**	**4584**	**48.81**	**100.00**	**1 012.08**	**12 893.92**