Species distribution modelling of horse mussels in Queen Charlotte Sound, Tory Channel and adjacent Cook Strait

Prepared for Marlborough District Council

October 2021

Climate, Freshwater & Ocean Science

Prepared by:
Owen Anderson,
Tara Anderson,
Sanjay Wadhwa.

For any information regarding this report please contact:

Owen Anderson
Scientist
Deepsea Ecology and Fisheries
+64-4-386 0863
Owen.anderson@niwa.co.nz

National Institute
of Water & Atmospheric
Research Ltd (NIWA)

301 Evans Bay Parade
Hataitai
Wellington 6021
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

NIWA CLIENT REPORT No:	2021363WN
Report date:	October 2021
NIWA Project:	MDC20302

Quality Assurance Statement		
	Reviewed by:	Juliet Milne
	Formatting checked by:	Alex Quigley
	Approved for release by:	Alison MacDiarmid

Cover photo: Horse mussels (Atrina zelandica), Long Island Marine Reserve, Marlborough Sounds [NIWA].

Contents

Tables

Figures

Executive summary

Horse mussels *(Atrina zelandica)* are a ubiquitous species of bivalve mollusc in the Marlborough Sounds, and one that is highly vulnerable to damage from physical contact with objects such as fishing equipment, anchors and moorings. Horse mussels can form dense beds that also support other sea life, to such an extent that some beds may be considered ecologically significant and worthy of special protection. To better understand the distribution of horse mussels within the Marlborough Sounds the Marlborough District Council commissioned NIWA to analyse horse mussel density data from recent camera surveys, and use these data along with a comprehensive set of environmental information from high-resolution bathymetry surveys in statistical models to describe the spatial distribution of their abundance.

The horse mussel density data were collected during four video surveys of Queen Charlotte Sound and Tory Channel undertaken in 2016–2018 to accompany and ground truth aspects of the NIWA-led HS51 bathymetry survey completed in 2017, and to investigate blue cod nursery grounds. Bathymetry data from the HS51 survey and derived parameters such as slope, seabed roughness, curvature, and hardness were the key environmental predictors in the spatial distribution models, and therefore the extent of the HS51 survey (Queen Charlotte Sound, Tory Channel, and a discrete adjacent area of Cook Strait) defined the spatial limits of the modelling. A further predictor, based on a hydrodynamic model of near-seabed current speeds in the Queen Charlotte Sound, was also used in the model.

The species distribution modelling combined the outputs of two-step hurdle models from two methods, Boosted Regression Trees (BRT) and Random Forests (RF), into an ensemble model to predict the spatial distribution of horse mussel densities (as percentage seafloor cover). The resolution used for the model outputs was set at a grid size of 8 x 8 m, primarily to approximately match the resolution of the video sample data which were largely compiled from time-segmented transects. Model performance was assessed for each method separately, using standard metrics, and model uncertainty was estimated using resampling methods which provides a separate grid to indicate areas where the model predicts more, or less, confidently.

As well as describing the methods used and the outputs of the model, a summary of historical information on horse mussel distribution across the study area is provided, based on a review of published and unpublished records.

The key predictor of horse mussel density in each of the component models was near-seabed current strength. The importance of the other predictor variables varied among model types, with distance to the nearest headland, seafloor rugosity, slope, depth, and Residual Autocorrelation (RAC, a derived variable which helps account for spatial autocorrelation in the sample data), all variously important. Performance metrics for the ensemble models indicated excellent fits to the data and the spatial predictions of horse mussel densities matched well to observations from the video surveys. Maps of estimated model precision generally associated areas of higher predicted density with higher levels of model certainty.

The successful application of this modelling approach, both in this study and in an earlier study which predicted distributions of bryozoans and the *Galeolaria hystrix* tube-worm across the same area, provides confidence that it can be used for other taxa for which abundance data have been collected. Alternatively, novel methods such as Joint Species Distribution Modelling could be applied to these data to examine the potential of simultaneously predicting distributions of multiple taxa at both species and community levels.

1 Introduction

Horse mussels (*Atrina zelandica*) are New Zealands largest (≤47 cm in length) endemic bivalve species (Hay 1990; Anderson et al. 2019). Horse mussels are found commonly in many coastal areas around much of New Zealand (Hay 1990; Anderson et al. 2019), where they live in muddy to sandy marine sediments in depths down to at least 100 m (Vooren 1975; Elvines et al. 2019; Morrisey and Fletcher 2019), although freshly dead horse mussel shells have been collected in a dredge from 200 m water depth, off Kaikoura (Hay 1990). While juveniles begin life completely buried, adult horse mussels become emergent with up to two thirds of their shell exposed above the seafloor (Hay, 1990). Horse mussels can form extensive beds, but can be impacted within the coastal environment by both land- and ocean-derived anthropogenic impacts, and have become increasingly rare - likely due to their known vulnerability and exposure to bottom fishing activities, such as scallop dredging and bottom trawling (Hay 1990; Jones et al. 2016; Anderson et al. 2019) and their susceptibility to changes in suspended sediments, particularly land-derived silts which are known to stress and kill horse mussels (Ellis et al. 2002, Hewitt and Pilditch 2004, Lohrer et al. 2006). Many horse mussel beds within the Marlborough Sounds have also declined in density and extent over time (Davidson et al. 2015; Anderson et al. 2019; DSIR *unpublished data*).

Horse mussel beds, which are defined as "*the occurrence of large shellfish in densities of ≥ 30% cover, over an area of 100 m^2 or more, or where catches contribute 30% or more by weight or volume in a single dredge tow or grab sample*" (MacDiarmid et al. 2013; Anderson et al. 2019), are considered ecologically important in ecosystem health and function (Davidson et al. 2011; MacDiarmid et al. 2013). For example, beds of horse mussels are important ecosystem engineers, stabilising soft sediments, filtering large volumes of water, sequestering nutrients, and supporting diverse and abundant macrofauna (Cummings et al. 1998; Norkko et al. 2006; Anderson et al. 2019). The emergent shells of horse mussels (both living and dead) are also known to provide attachment surfaces for diverse and abundant flora and fauna, including other habitat-forming species, such as sponges and reef-forming bryozoans (e.g., sponges, bryozoans, macroalgae, hydroids and ascidians) (Davidson et al. 2010; Hay 1990; Anderson et al. 2019), and act as refugia for small fishes, including nursery habitats for juvenile blue cod (Morrison et al. 2014; Anderson et al. 2019). Horse mussel beds are highly vulnerable to bottom fishing activities, which can remove and dislodge and damage horse mussels and can have extensive and intensive impacts to these benthic communities (e.g., Hay, 1990; Anderson et al. 2019). Beds of horse mussels also have often pivotal roles in ecosystem function and health (see reviews in MacDiarmid et al. 2013, Morrison et al. 2014, and Anderson et al. 2019), where the loss of horse mussel beds leads to a loss of community and ecosystem-level function (Turner et al. 1999; Cummings et al. 1998; Morrison et al. 2014; Anderson et al. 2019).

Horse mussels are known to be patchily distributed at three spatial scales (Hay 1990). They are known to settle in localised clumps interspersed by soft-sediments (cm–m scale), with many clumps co-occurring to form locally dense clusters (100–200 m scale), and many patches occurring within larger beds (hectares scale). Consequently, estimating horse mussel densities depends greatly on the explicit area over which densities are estimated. For example, counts recorded from localised areas (cm–m scale) have indicated very high localised densities (e.g. 20 indiv. within 0.2 m^2 in 3.5 m depth at Te Kapa Inlet, Mahurangi Harbour (Cummings et al. 1998), and 80 indiv. per m^2 (described in Lohrer et al. 2010)), while horse mussel densities recorded over larger spatial areas – that include dense clusters as well as the interspersed areas of bare sediment – will be significantly lower (e.g. 20 indiv. within 0.2 m^2 compared with an estimated 12 indiv. per m^2, based on Cummings et al. 1998).

Consequently, comparing horse mussel densities between different studies in space and time is complicated and requires knowledge of the scale of measurement, and the avoidance of density comparisons among surveys undertaken at different spatial scales. This issue of density relative to measurement-scale means that terms such as “dense”, “moderate”, “low” or “sparse” should be used, and interpreted, with caution.

Marlborough District Council (MDC) has designated a set of defined areas at a range of locations around the Marlborough Sounds as Ecologically Significant Marine Sites (ESMS) that may warrant some level of protection through provisions in the proposed Marlborough Environment Plan (pMEP)[1]. These sites are arranged into several classifications (Algae, Bird, Fish, Invertebrate, Physical, Plant, Shark) depending on the type of habitat identified. Under a protocol established by MDC, for newly discovered habitat and community sites to be considered ecologically significant in the Marlborough region and added to the pMEP, one of the following four criteria must be ranked M (Medium) or H (High): representativeness, rarity, diversity and pattern or distinctiveness. Sites identified as ecologically significant then need to be evaluated relative to their vulnerability to seabed disturbance, categorised in the pMEP as:

- A) Sites intolerant of most forms of seabed disturbance (including anchoring and all forms of dredging and trawling),
- B) Sites generally intolerant of benthic physical disturbance, but can tolerate occasional anchoring, or
- C) Sites that cannot tolerate heavy benthic physical disturbance but can tolerate disturbance from light (< 25 kg) gear.

Once these criteria have been identified, MDC’s protocol requires the spatial extents of proposed ecologically significant sites to be plotted on maps. Sites identified as meeting criteria A and B also require a buffer-zone around them.

For key biogenic species that are known to be vulnerable to physical disturbance, MDC requires detailed information on their known distribution as well as their predicted distribution within the Marlborough region. A recent report (Anderson et al. 2020c) provided such information for two such biogenic taxa, *Galeolaria hystrix* tubeworm mounds and bryozoan mounds, across the extent of the recent detailed HS51 bathymetric survey of the area (Neil et al. 2018a,b) for which a suite of relevant predictor variables are available and where four video surveys of seabed habitats were recently carried out. For horse mussels, MDC considered an examination of historic versus recent site information would help evaluate the current relevance of existing ESMS in the context of notable biogenic areas not yet designated as ecologically significant.

The MDC therefore engaged NIWA to:

1. Examine and report on horse mussel distributions observed in the recent video surveys, including provision of maps of distributions, photographs of horse mussel habitats, illustrations of relationships with seafloor Multibeam Echo-Sounder (HS51 MBES) data layers from the bathymetric survey (as described here and in Neil et al. 2018a,b), and summary tables of notable historic and present horse mussel sites.

[1] https://www.marlborough.govt.nz/your-council/resource-management-policy-and-plans/proposed-marlborough-environment-plan

2. Undertake predictive distribution modelling of horse mussels within the HS51 bathymetric survey area, using sophisticated statistical modelling techniques as applied recently to *Galeolaria hystrix* tubeworm and bryozoan mounds in the area (Anderson et al. 2020c).

This report addresses these two objectives and in particular describes the application of species distribution modelling to predict densities (i.e. abundance) of horse mussels across a broad area of the Marlborough Sounds: Queen Charlotte Sound/Tōtaranui (QCS), Tory Channel (TC), and the adjacent Cook Strait (CS). Building on the work of Anderson et al. (2020c), models were also constructed using newly available spatially-rich occurrence/absence data for horse mussels from the four recent video surveys (MDC18, CB17, BT17 and HS51 - reported in Anderson et al. 2020a) and the extensive spatial coverage of the high-resolution MBES data (e.g. bathymetry, backscatter, slope, rugosity, reported in Neil et al. 2018a,b) along with the detailed hydrodynamic modelling outputs (e.g. near bed current strength) reported in Hadfield et al. (2014) and Hadfield (2015).

In addition to the report itself, spatial maps of the predicted distributions of horse mussel habitats (and associated uncertainty), along with locality data for the observed horse mussel occurrences and rank-abundance, are supplied separately as a set of ArcGIS compatible files.

2 Methods

2.1 Review of historic information

Literature published in scientific journals, “grey literature” reports (e.g. baseline and monitoring reports), and unpublished data (primarily NIWA-held DSIR log-books) was reviewed to obtain an initial picture of the historic distribution of horse mussels and horse mussel beds within the study area. Information from this review was supplemented by discussions with researchers and local fishers with relevant knowledge of the area and species.

2.2 Horse mussel video surveys

The horse mussel observations used to build models of predicted abundance were derived entirely from four video-camera surveys of the seabed completed during the period December 2016 to October 2018. Each of the four video surveys were used to measure abundance of readily identifiable seafloor biota (as presented in Anderson et al. 2020a), including horse mussels (this study). A brief description of these surveys follows, with further details available in Anderson et al. (2020a):

MDC18 ground-truthing survey (September–October 2018)

NIWA’s CBedcam and Coastcam underwater video systems were used to survey 150 drop-camera sites to ground-truth the high-resolution multibeam maps provided to MDC through the HS51 bathymetry surveys (Neil et al. 2018a, b), and to visually characterise habitats and communities focusing on areas not previously surveyed by the studies below (Anderson et al. 2020a; see maps of site locations in Appendix A, and zoomed-in maps in Appendix B, Appendix C and Appendix D).

BT17 bottlenecks survey (March–April 2017)

This was the first of two surveys under NIWA’s MBIE-funded “Bottlenecks” research programme investigating blue cod nursery habitat in the Marlborough Sounds in depths < ~30 m. The BT17 survey used a beam trawl fitted with 2 GoPro-3 video cameras to collect fish and characterise seafloor habitat and benthic biota at 34 sites (within trawlable habitats) across the study area (see map of site locations for BT17 in Appendix E).

CB17 bottlenecks survey (April–May 2017)

Th second of the two “Bottlenecks” surveys employed NIWA’s towed CBedcam to survey more rugged untrawlable habitats, in depths <~30 m; where video observations were collected at ~30-sec intervals along transects at 43 sites across the study area (see map of site locations for CB17 Appendix F).

HS51 bathymetric survey (December 2016 and May 2017)

NIWA’s Dropcam and Coastcam underwater video systems were used to survey 132 sites within the study area (See map of site locations for HS51 in Appendix G): primarily to determine seabed type and texture (Neil et al. 2018a, b) and ground-truth MBES maps (Anderson et al. 2020).

Data were limited to these four recent surveys in order to represent the current distribution of the species within QCS. While it may have been possible to convert some of the more historic observational data into presence/absence/abundance data suitable for the models, around 37 years have elapsed since the first data were collected and any changes in the seafloor environment during that time will have affected habitat suitability and species presence/abundance in many of the sampled areas, and potentially bias the results.

2.3 Habitat suitability modelling

Two commonly used machine-learning model approaches (Boosted Regression Trees (BRT) (Elith et al. 2008) and Random Forests (RF) (Brieman 2001)) were used to model the spatial distributions of horse mussels across the HS51 study area, following methods described in Anderson et al. (2020a,b).

The quality of the input data allows the model to estimate horse mussel abundance, rather than just a measure of relative suitability as is typically produced by models using only presence/absence or presence/background data. However, fishing and other physical disturbances not accounted for in our model are likely to have had a significant influence on the present-day distribution and abundance of this species, so that some unsampled but highly fished areas that are predicted by the model to have a high density of horse mussels may in fact have only low densities. For this reason, we prefer to use the term Habitat Suitability (HS) rather than Species Distribution to describe our model predictions.

Models were based on percent cover abundance data collected from the combined survey sites and the full-coverage, high-resolution spatial grids of the physical and environmental parameters: specifically NIWA's MBES data layers (bathymetry, backscatter, slope, rugosity, seafloor classifications etc.), from Neil et al. (2018a,b); the modelled hydrodynamic current layers (near-bottom current strength from Hadfield et al. (2014); Hadfield 2015)) and the two derived spatial layers (distance to headland, distance to reef) for the HS51 study area.

A recent study used some of the data available for the current analysis to create models predicting habitat suitability (but not abundance) for horse mussels in the same area of the Marlborough Sounds (Ribo et al. 2021), using a different modelling technique, Maxent (Phillips et al. 2006). The results of this are briefly described, in comparison to the outputs from the more complex model produced in the current study.

2.3.1 Post-processing of observational video data

The video field-surveys, recorded observations of horse mussels either for a single site position (i.e. HS51 and BT17 sites), or along the length of each video-transect (i.e. CB17 and MB18). Data collected during the HS51, BT17, and CT17 surveys initially recorded only the occurrence (presence/absence) of horse mussels along each transect, while the MDC18 survey also recorded rank-abundance (0, 1-2, 3-10, >10). For the purposes of modelling horse mussel distributions in this study, we first post-processed these data sets to provide rank-abundance of all horse mussel records for all four surveys following the methods of the MDC18 survey (described in full in Anderson et al. 2020a). In addition, for quality assurance and control (QA/QC) purposes: 100% of all horse mussel records from the MDC18 *'real-time'* field surveys, along with the full transect if horse mussel beds were present within the site, were assessed/post-processed to ensure all data records were correct (see Appendix H for a summary of the rank abundance data for MDC18). Rank-abundance for all surveys was then re-categorised for input into models, so that rank-abundance is recoded as % cover at the following levels: 0, 1, 2, 3, 5, 10, 15, 20, 25 and 30. Higher % cover ranks were not required as no sites supported > 30% cover.

2.3.2 Physical/environmental predictors

Predictor variables used in the HS models were based on a combination of multibeam bathymetry and backscatter; bathymetry and backscatter derived rasters produced from the HS51 multibeam survey of QCS and Tory Channel in 2017 (Neil et al. 2018a,b); and derived currents from hydrodynamic models of the survey area (Hadfield et al 2014). Specifically, these included:

- A numerical classification of seafloor sediment types (combination of grain size and seafloor reflectivity/hardness) based on an analysis of backscatter data with sediment grain size from the HS51 survey data (Neil et al. 2018a,b);
- Modelled near-bottom current strength (Hadfield et al. 2014 and Hadfield 2015);
- Percent composition of each sediment type (sand, gravel, silt etc.,) based on interpolated values from HS51's sediment grab sampling (Neil et al. 2018a,b); and
- Spatially-derived grids of the calculated distance to the nearest cell comprising rocky reef; and distance to the nearest cell at a headland.

To reduce model complexity and find a balance between providing models with as much explanatory power as possible while also minimising the fitting of models to noise rather than signal, a subset of the environmental variables (Table 2-1) was selected based on knowledge of species ecology and the removal of highly correlated variables.

Table 2-1: Description of the environmental variables used in the HS models. Seafloor rugosity (or VRM) = Vector Ruggedness Measure (described in Neil et al. 2018a,b). Variables: [1] = HS51 MBES bathymetry (described in Neil et al. 2018a); [2]= MBES derivatives (as described in in Neil et al. 2018a,b); [3]=interpolated raster from HS51 sediment grab samples (Neil et al. 2018a); [4]=Seafloor classifications from supervised classification of HS51 MBES backscatter intensity in combination with HS51 sediment grab samples and depict the sediment type and hardness across the study area; [5]=Hydrodynamic model outputs for near-bottom current speed (i.e., ≤5 m above the seafloor); [6]=distances to nearest rocky reef/headland, derived from coastline and seafloor classification.

Environmental variables	Units	Native resolution	Source
[1]Depth	m	2x2 m	NIWA
[2]Slope	Degrees	2x2 m	NIWA
[2]Slope standard deviation	–	2x2 m	NIWA
[2]Seafloor rugosity (VRM)	–	2x2 m	NIWA
[2]Curvature	–	2x2 m	NIWA
[3]Percent sand	%	2x2 m	NIWA
[4]Seafloor classification	-70 to 10	2x2 m	NIWA
[5]Near-bottom current speed	m/s	0.5x0.5 m	NIWA
[6]Distance to rock	m	2x2 m	NIWA
[6]Distance to headland	m	2x2 m	NIWA

As observations within-sites were collected at close spatial intervals (<30 sec) along tow-video transects across the survey area (specifically CB17 and MD18), closely neighbouring data points are likely to be more similar to each other than to data points further apart (e.g. between sites), and thus may provide less independent information. Consequently, to improve the fit of the HS models, a further predictor was created to help account for this spatial autocorrelation (the tendency for areas or sites that are close together to have similar values). This Residual Autocorrelation (RAC) variable therefore, represents the spatial correlation amongst the residuals from an initial model based on the environmental variables alone (Crase et al. 2012). The inclusion of this variable has been useful in measuring the relative influence of spatial autocorrelation in predicting habitat suitability/species distributions from other video surveys (e.g. Rowden et al. 2017, Georgian et al. 2019), and ensuring that these predictive models are not overfitting these types of fine-resolution data.

2.3.3 Model structure, performance and outputs

The BRT and RF species distribution models were applied to the presence/absence data at all sites, and then separately to the percent cover data at presence locations only. Two component models of horse mussel distributions are therefore produced; one describing the probability of presence, the other the predicted percent cover. In the binomial (presence/absence) models, the response variable had values of either 0 (absence of the taxon) or 1 (presence of the taxon). In the percent cover models, the response variable was a logit transformation, log(y/(1-y)), of the estimated percent cover (rank-abundance) values from the observations; this transformation produces a near normal distribution of the response variable while suppressing the prediction of non-sensical values (less than 0 or over 100%) when back-transformed (Warton & Hui 2011, Anderson et al. 2020b).

Overall abundance within each cell of the environmental grid was then predicted from each model type by combining the predictions of the two models using simple multiplication, a method known as a hurdle model.

A final, ensemble model of the RF and BRT hurdle models was then created by taking a weighted average of the predictions from each model in such a way as to give greater weight to the better performing model overall, as well as to the model with the least uncertainty at the cell level. These weights therefore comprised two components: 1) the performance value for the model (AUC or R^2, see below) applied to all cells equally, and 2) the prediction uncertainty (calculated as the coefficient of variation [CV]), applied to individual cells. These two components were given equal “weight” in the overall weighting.

Model resolution

Although the bathymetry and derived terrain metrics were produced for the study area at a grid resolution of 2 x 2 m (approx. 650 M cells), transect sample data were compiled at coarser resolution (the highest based on 15 sec observation segments at a towing-speed of 0.5–1 knot — equivalent to about 4–8 m). To align the resolution of the sample data with that of the predictor variables, model outputs were produced at a resolution of 8 x 8 m (approx. 25 M cells). This also alleviated computer processing constraints when carrying out hundreds of simulations for the calculation of model uncertainty (see below). The New Zealand Transverse Mercator 2000 projection (EPGS:2193) was used as the coordinate reference system for all outputs.

Model performance and precision

Performance of the presence-absence models was measured by AUC, a threshold independent assessment of the ability of the model to rank occurrences above absences. For the percent cover models the model R^2 value was calculated. We applied a bootstrap technique to estimate uncertainty in the predictions. For each model type (BRT/RF, presence-absence/percent cover) 100 random samples of equal size to the original data set were selected from the sample data, with replacement, with separate hurdle models created from each sample. For the presence-absence component this was done in such a way as to retain the same proportion of presence and absence points as in the original data set. In this way 100 separate estimates of percent cover are produced for each cell of each model (BRT/RF) from which the mean value, the standard deviation (SD), and CV can be calculated.

2.3.4 Distribution maps and GIS polygons

All maps were created in ESRI ArcGIS version 6.6. Spatial files were created to illustrate the distribution of horse mussels within the study area. Habitat suitability models, using the final ensemble model, produced two continuous-raster (tiff) files for plotting in ArcGIS:

1. The predicted % cover distribution for horse mussels within Queen Charlotte Sound and Tory Channel and adjacent Cook Strait; and

2. The precision (or uncertainty) of the predicted distribution (i.e., how well the model predicted the distribution).

The final raster layer was then plotted in ArcGIS with a colour swath/classification depicting 1) the relative percentage cover and the degree of uncertainty, with associated ArcGIS layer files (*.lyr)[2] created for each raster.

[2] Defining the symbology and the colour swaths used to categorise these layers.

3 Results

3.1 Review of historic information

Horse mussels have been recorded across much of the Marlborough Sounds, where they are commonly found in muddy sands and mud from low water to ≤ ~100 m water depth (Elvines et al. 2019; 2021; Robertson 2021), and in some locations form extensive beds (Hay 1990b; Davidson et al. 2010a,b; 2011; 2015; Robertson 2021; also see Appendix I). The highest density horse mussel beds have been reported outside the Sounds, on offshore raised sediment banks in the outer Sounds (e.g. Appendix I - provides representative images of dense horse mussel beds from east of Chetwode Island in the outer Sounds), and on deeper sediment slope further offshore (Robertson 2021; Elvines et al. 2021).

Broad-scale horse mussel surveys using mainly dredges, with some scuba diving, were undertaken across the Marlborough Sounds in 1983 by DSIR researchers (Hay 1990; Hay et al.[3] *NIWA unpublished data*) with subsequent targeted dive surveys undertaken between 1983 to 1989, to examine in situ horse mussel densities, nearest neighbour clustering, and to set up and monitor horse mussel tagging. These studies identified and documented horse mussel beds in several locations across QCS (Table 3-1), with a subsequent focus on Motuara Island, East Bay and Onahau Bay (Hay et al. 1990 and McKnight and Grange 1991; *unpublished DSIR logbooks*[4]. In 1989-90, a broad-scale collaborative SCUBA diver and snorkelling survey across the Marlborough Sounds (360 sites) was led by the Department of Conservation (DOC - Clinton Duffy, *unpublished data*). While most of the information collected from these surveys has remained unpublished, some has been included in the descriptions of Ecologically Significant Marine Sites (ESMS) in Davidson et al. (2010; 2011; 2015 – based on historical *pers. comm.*), and some has been used to describe some changes in significant habitats (e.g. in the vicinity of Motuara Island, Davidson et al. 2015).

Common occurrences of horse mussels in depths of 10–20 m have also been recorded across much of the HS51 bathymetric survey area in low densities (0.3 individuals per m^2 from 25 sites, Hay 1990; Davidson et al 2011; 2015). Hay (1990) described densities of horse mussel sites within the HS51 survey area ranging from 1–5 per 100 m^2, with localised densities of up to 7–13 per m^2. Highest densities were found in Onahau Bay, off Grove Arm in the inner Sounds, with lower density beds recorded at the NW entrance to QCS (1–5 per m^2) (Hay 1990). Haggitt (2017) described horse mussels as distributed in "*isolated patches to the north and along much of the western coastline of the Kokomohua Islands in coarse sand and shell-hash habitat adjacent rocky reef*".

Numerous localised studies have also described common occurrences of horse mussels in water depths of less than 40 m in QCS and TC (e.g. Davidson et al. 2011 p102; Clark et al., 2011; Morrisey & Berthelson 2016; Haggitt 2017), with some horse mussels recorded in depths of 40–50 m (Hay 1990) and down to 80 m in some outer Sounds locations (Elvines et al. 2019; Morrisey et al. 2019), but Hay (1990) suggested horse mussel densities in depths greater than 22 m in QCS were likely to be low. Davidson et al. (2011 p102) also report the presence of horse mussels within several TC embayments (Maraetai, Onapua, Erie, Oyster and Te Rua Bays), and see also Morrisey et al. (2019) for a useful summary of known horse mussel beds in the area.

[3] Hay et al. refers to surveys led by Cameron Hay, Rod Singleton, Ken Grange and Rob Murdoch*; Survey logbooks and some data now held by NIWA*).

[4] *DSIR Atrina I* - benthic dredge and SCUBA diver surveys (DSIR Cruise No. 1153, Led by Cameron Hay [HS51 survey area: sites T416-T515]). *DSIR Atrina I-XIV* – benthic SCUBA diver surveys (1984-1990; DSIR cruise No. 1153, 1159, 7110, 7111, 7112, 7113, 7115, 7129, 7130a, 7132).

Beyond the inner Marlborough Sounds, dense horse mussel beds have been reported from various other outer QCS bays, as well as Port Gore (Hay 1990). Moderate to low density beds have also been reported in East Bay (Hay 1990 Davidson et al. 2010a,b, 2011). An expansive horse mussel bed with moderately high densities (17–34 per m^2) was also recorded on the Outer Sounds banks at a site east of Chetwode Islands (latitude -40.9143, longitude 174.1258) during the BT17 surveys, with 37 horse mussels collected having a mean shell length of 234.8 mm ± 40.7 SD (range 155-290 mm).

An MPI dredge survey for dredge oysters (*Ostrea chilensis*) in 2016 found horse mussels to be present in several QCS locations (Onapua Bay, Maraetai Bay, Bay of Many Coves, Ship Cove/Motuara Island), as well as in Pelorus Sound (Guards Bank), Port Gore, and around the Chetwode Islands (NIWA/MPI, unpublished data).

Loss of horse mussel beds within the study area have also been described (Davidson et al. 2010a; 2011; 2015). Horse mussel distributions are known to overlap with other commercially harvested bivalve species, including scallops, dredge oysters and green-lipped mussels, and are a common bycatch in dredge fisheries (Hay 1990; Davidson et al. 2010a; Anderson et al. 2019). Between the 1980s and 2015, many of the horse mussel beds recorded from DSIR and DOC surveys (particularly areas adjacent to high scallop dredging areas, such as Motuara Island) had declined significantly in extent (Davidson et al. 2015). For example, the 415 ha area delineating horse mussels north of Motuara Island in depths of 6–20 m (with densities highest in 17-18 m) (ES Site 7.4 of Davidson et al. 2010a), had all but disappeared by 2014 (reduced ESMS-7.4 to 12.7 ha, to delineate the reef and kelp communities – Davidson et al. 2015).

MPI scallop surveys, undertaken between 1994 and 2019 within the Marlborough Sounds, have regularly collected (mostly low numbers) of horse mussels as bycatch, along with reef-forming bryozoans (commonly referred to as 'coral' by fishers), sponges and macroalgae. Horse mussels have also been collected as bycatch from areas in and around scallop beds (e.g. around Motuara Island, the Bay of Many Coves, and the Bank in QCS northeast of the junction into TC). Hay (1990) described dredge fishing (used in the Marlborough Sounds for collecting scallops both commercially and recreationally) as having a devasting impact on horse mussel beds and their dependent communities. Hay (1990) provides detailed descriptions of bottom fishing impacts on horse mussel beds, based on both experimental dredging across a horse mussel bed supporting 3–5 horse mussels per m^2, and descriptive observations of fishing practices from past fishers (described in Hay 1990). Hay (1990) describes scallop dredges quickly filling-up with mangled shells and epibiota (typically described as '*rubbish'*, i.e., of no value to fishers), with fishers then avoiding these areas.

As horse mussels are fragile with their emergent shells extending up above the surrounding sediments, they are extremely vulnerable to breakage, dislodgement and collection/removal by bottom fishing activities (Hay 1990, Thrush and Dayton 2002, review in Anderson et al. 2019). If dislodged whole, the horse mussel is unable to re-bury, and subsequently dies (Hay 1990). The epibionts (e.g. invertebrates and macroalgae such as bryozoans, sponges, seaweeds, hydroids and ascidians that attach to the exposed shells of horse mussels) can also get dislodged and damaged (Hay 1990*; C. Hay pers. comm*.). Hay also describes fishers reports of the *possible common-practice* of deliberately flattening these biogenic foul-grounds prior to fishing them for scallops (Hay 1990). However, many of these seafloor areas had also been subjected to bottom pair-trawling prior to Hay's 1983–89 horse mussel surveys (Hay *pers. comm.*), while commercial and recreational scallop dredges continued to operate in these areas until the recent closure of the scallop fishery (SCA7) in July 2018 (Fisheries New Zealand, 2019).

Table 3-1: Descriptions of horse mussel beds based on historic accounts. Descriptions are based on published literature as well as some unpublished accounts from DSIR logbooks held by NIWA.

Area	Location	*Atrina* density	Description	Citation
Outer QCS	NW entrance to QCS	Moderate	Moderately dense *Atrina* bed, with 1-5 horse mussels per m^2 Hay (1990) mentions high densities of horse mussels at the north-western and western approaches to QCS.	Hay (1990)
Outer QCS	Motuara Island	Mod-high	In 1983–1989 an extensive *Atrina* bed was present in water depths of 6-20 m, with highest densities in 17–18 m, that also supported notable amounts of attached *Macrocystis*[12]. In 2011, a 300.6 ha area in 0-21 m depths was delineated [*ESMS-7.4*], based on[1a-b]. This encompassed the northern reef and macroalgal community (12.7 ha) and the *Atrina* bed (287.9 ha) and encompassed the northern reef and depths of 0–21 m, and described as the largest known area within the Cape Jackson biogregion[3]. *Atrina* were recorded within 9-12 m[(3)]. By 2015, although horse mussels were still present over most of the ESMS-7.4, abundance was low[4]. ESMS-7.4 was reduced to only incl. the northern reef and its macroalgal communities[4].	[1]Fig. 3 in Hay (1990) [2]NIWA *Unpub. data* [3]Davidson et al. (2011), p115 [4]Davidson & Richards (2015), p42-43
Outer QCS	Long Island Marine Reserve. (NW side between Long Island & Kokomohua Island)	Patchy, sparse-moderate	Sparse to moderate density *Atrina* bed in depths of 10–20 m covering 0.3 km^2. Described as "*isolated patches to the north and along much of the western coastline of the Kokomohua Islands in coarse sand and shell-hash habitat adjacent rocky reef*" (Fig. 3.4e in Haggitt 2017).	Haggitt (2017)
Outer QCS	Ruapara Bay, Onauku Bay, East Bay (NE)	Not specified	*Atrina* bed, most dense in 12 m water depth[12]. Tagging and *Atrina* collections [19 m depth] during 1983–89[2]. Bed(s) within the broader *Ecol. Significant Sites 4.24 [Onauku Bay Head],* this area also known to have high numbers of scallops, with giant lampshells in deeper areas. *Atrina* present, but limited by recreational scallop dredging[3]	[1]Hay (1990) [2]NIWA *Unpub. data* [3]Davidson et al. (2011), p100
Outer QCS	Te Aroha Bay, Otanerau Bay, East Bay (SE)	Moderate	Moderate numbers of horse mussels (0.5 per m^2) of medium size area[3,4 (review in 5,6)]. *Atrina* encrusted with ascidians, sponges and hydroids[5], in depths of 6-25 m. Found in ESMS-4.21[Te Aroha Bay] and 4.23 [Matiere Pt].	[1]Hay (1990); [2]NIWA *unpub. data* [3]Davidson & Pande (2002) [4]Davidson & Richards(2015) [5]Davidson et al. (2011), p94, 99 [6]Davidson et al. (2010b)
Outer QCS	Puriri Bay, Otanerau Bay, East Bay (SW)	Common (not specified)	Horse mussels and scallops common in wider bay[3]. SCUBA transects in 5–16 m, with *Atrina* collections made in 12 m (1986)[1,2]. Common occurrences in these bays[3].	Hay (1990)[1]; *NIWA Unpub. data*[2]; Davidson et al. (2011)[3 (based on quick site visit)]

Area	Location	*Atrina* density	Description	Citation
Inner QCS	Between headlands Lochmara Bay	Sparse	*Atrina* very sparse (8 sighted in 3 min dive) [Dive Site-T657, 9/10/1984] Common occurrences[3]	[1]Hay 1990; [2]*NIWA Unpub. data*; [3]Davidson et al. (2011), p97.
Inner QCS	West Bay, Lochmara Bay	Sparse	Atrina very sparse, weedy bottom (Hay logbook notes Site T658 1984)	*NIWA Unpub. data*
Inner QCS	Onahau Bay	Dense	Hay (1990) also describes an exceptionally dense bed (*defined as 7–13 horse mussels per m*^{2}) - although it is unclear what data these descriptions are based on. Indicated the condition of horse mussels in high density beds are usually poor with high mortality – but it is unclear whether condition was determined at this particular site	Hay (1990)
Inner QCS	Mistletoe Bay Onahau Bay	Moderate	Moderate density *Atrina* bed in centre of bay in 16 m[1], based on bounce dive. Notes "weedy bottom sloping to 16 m" [Dive Site-T653, 9/10/1984]	[1]*Atrina* surveys, C. Hay et al.[5] *NIWA Unpub. Logbook*.
Inner QCS	Fence Bay Onahau Bay	Dense	Very high density of *Atrina* similar to site-T652 [Dive Site-T654, 9/10/1984]	[1]*Atrina* surveys, C. Hay et al. *NIWA Unpub. Logbook*.
Inner QCS	Fence Bay Onahau Bay	Moderate	Moderate density of *Atrina* in centre of bay in 12 m[1], Weedy bottom sloping to mud in centre of bay [Dive Site-T655, 9/10/1984]	[1]*Atrina* surveys, C. Hay et al. *NIWA Unpub. Logbook*.
Inner QCS	Shallow embayment East side of Onahau Bay	Dense	Exceedingly high density of *Atrina* (160 live *Atrina* per 5 m^2 equating to 32 per m^2) [Dive Site-T656, 9/10/1984]	[1]*Atrina* surveys, C. Hay et al. *NIWA Unpub. Logbook*
Inner QCS	Okiwa Bay Grove Arm	Not specified	Patchy beds	Hay (1990)
Inner QCS	Grove Arm (unspecified location)	Dense	>10 horse mussels per m^2	Davidson et al. (2011), p44.
Inner QCS	Bottle and Umungata Bay		Patchy horse mussels within EES-4.3	Davidson et al. (2011), p94-96
Inner QCS	Ngakuta Bay near Picton	Not specified	1985 Site T705, no depth provided *Ecol Significant Sites 4.5 [Ngakuta Bay], 4.6 [Ngakuta Pt].*	Hay (1990)

[5] Hay et al. refers to DSIR surveysin the 1980-90's led by Cameron Hay, Rod Singleton, Ken Grange and Rob Murdoch*; Survey logbooks and some data now held by NIWA*). Specifically *DSIR Atrina I* - benthic dredge and SCUBA diver surveys (DSIR Cruise No. 1153, Led by Cameron Hay [HS51 survey area: sites T416-T515]); and *DSIR Atrina I-XIV* – benthic SCUBA diver surveys (1984-1990; DSIR cruise No. 1153, 1159, 7110, 7111, 7112, 7113, 7115, 7129, 7130a, 7132).

Area	Location	*Atrina* density	Description	Citation
Inner QCS	Iwirua Pt to Wedge Pt, Grove Arm		[1]Horse mussel bed in 18-30 m depth, supporting a dense bed of large brachiopods (*Neothyris lenticularis*) [2]Wedge Point also supports elephant fish spawning area and giant lampshell habitat *Ecol Signficant Sites 4.7 [Iwirua Pt], 4.8 [Wedge Pt], 4.9 [Wedge Pt mounds]*	[1]Davidson et al. (2011), p92-96 (based on Personal communication); [2]Duffy et al. (*Unpub. data*)
Outer QCS	Onauku Bay Head East Bay	Low	Common occurrences	Davidson et al. (2011)
Outer QCS	Onapua Bay, Maraetai Bay, Bay of Many Coves, Ship Cove/Motuara Island	(not specified)	Dredge survey, presence only recorded	NIWA/MPI *Unpub. data*

3.2 Horse mussel video surveys

The video surveys carried out between December 2016 and October 2016 identified that within the HS51 study area, horse mussels (i.e., at least 1 individual) occurred at 31% of the 358 sites surveyed. However, although horse mussels were a consistent component of the benthos across much of the survey area, high density beds of horse mussels were not recorded at any sites surveyed. Several notable horse mussel beds were however recorded but these supported densities of ≤ 30% cover. Several locations including East Bay, Kumutoto Bay, and Grove Arm supported low to moderate density horse mussel beds (20-30% cover) (Figure 3-2). Although no densely populated horse mussel beds were recorded during any of the four surveys, several low-density horse mussel beds were recorded within the survey area in a range of locations from inner to outer QCS (Table 3-2; Figure 3-1), with many of these recorded in or near known historic beds (Table 3-1). Horse mussels were recorded in all four surveys, over a water depth range of 4.7–59.4 m (mean 22.4 m ± 0.4 m SE). The shallowest occurrence (4.7 m) was recorded in the inner QCS (inner-most Site in Grove Arm, within a cockle bed – Site MDC18-Q197), and the deepest occurrences were recorded on the channel floor in mid-sections of Tory Channel (1 individual from a dropcam at HS51-B4, 59 m) and outer-QCS within a dense brachiopod field on a deep slope near the entrance to Resolution Bay (MDC18-Q47, 52 m).

Horse mussel occurrence was consistently high within QCS (79% of sites and 14% of records in the inner-QCS; 68% of sites and 6.1% of records mid-QCS; and 49% of sites and 5.5% of records in outer-QCS). In contrast, Tory Channel sites generally had low occurrence (<25% of sites, <3.7% of records), and no horse mussels were recorded out in the Cook Strait (see Table H-1 for a summary of MDC18 survey results). However, total within-site occurrence for transect segments was low (6.7% of all records) (MDC18, CB17 and BT17 surveys[6]).

Horse mussel beds in mid-outer QCS (e.g. along the inner side of East Bay and north side of Long Island) supported a range of taxa, the most notable being juvenile blue cod (e.g. Figure 3-1c), along with red sea urchins (*Pseudechinus albocinctus*) and unidentified species of strappy red algae (dense at some East Bay sites, e.g. BT17-QC21). On the expansive outer QCS Bank (known by fishers as the Duck Pond), very low numbers of horse mussels were recorded, along with low numbers of dead and sometimes broken horse mussel shells – encrusted with colonial ascidians (e.g. Figure 3-1 a, c, e, I). In areas where bryozoan patch reefs were present along the outer-Bank section of the Duck Pond, horse mussels were regularly seen partially to completely encrusted by the Tasman Bay Coral, *Celleporaria agglutinans*, while within the centre of small to large bryozoan patch reefs the tops of relict and occasionally living horse mussels could be distinguished (e.g. Figure 3-1c). Horse mussel shaped structures within large solid bryo-reefs were also common, indicating that horse mussels may be a common (and likely important) hard structure for reef-building bryozoa to initially settle and grow on – in these otherwise extensive soft-sediment areas. Consequently, damage and loss of horse mussels from outer Bank sites may have important bottom-up impacts on successional communities.

In the inner Sounds, several low to moderately dense horse mussel beds were recorded. These included a bed within Kumutoto Bay (Site C29). In contrast to outer QCS, living horse mussels within the inner Sounds, such as Kumutoto Bay, generally had little to no epibionts encrusting their shells.

[6] HS51 records are not included here. Horse mussels were recorded at only three HS51 sites. The very short duration footage of the HS51 dropcam sites and the reduced visibility due to natural light at many sites was together deemed not conducive to determining the occurrence of horse mussel beds (espescially as horse mussels were patchy and in low densities – as confirmed by the other three surveys).

One exception was found at one inner QCS site (CB17-C32), where horse mussels were partially to heavily encrusted with a fine-branching hydroid.

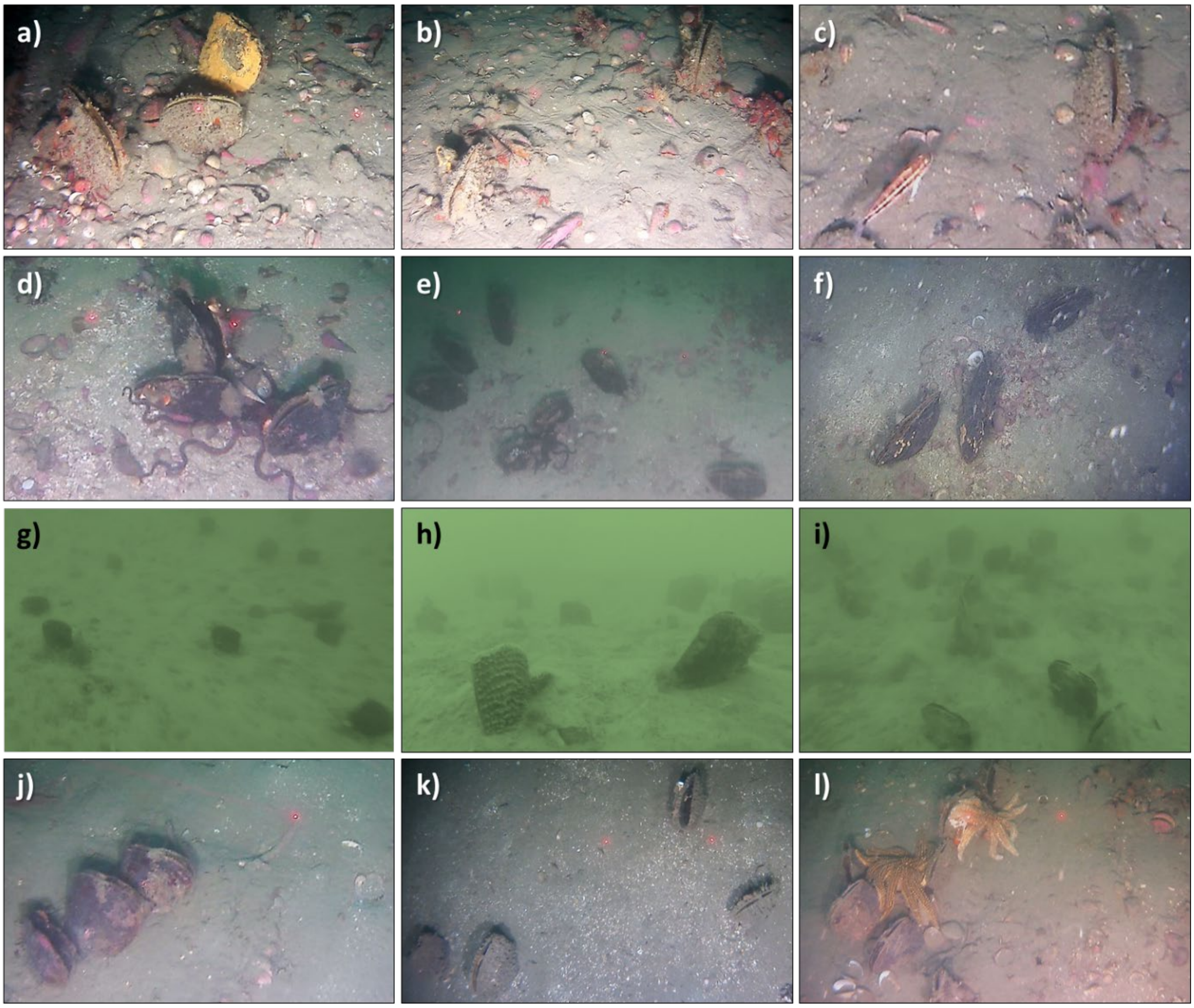


Figure 3-1: Example of horse mussel beds in QCS. Images were collected from several surveys. a-c) Low-density horse mussel bed on NW side of Long Island between Kokomohua Island, inside the Long Island Marine Reserve (LIMR) in outer-QCS (CB17-C04), with juvenile blue cod [c]; d-g) several beds within East Bay: d) extensive moderate-low density horse mussel bed from Ruapara Bay (CB17-C09); e, g) low-moderate density bed in bay just south of Otonga Point (BT17 survey, Site QC19); f) patchy low density bed in Te Aroha Bay, Otanerau Bay (CB17-C10); h-i) extensive bed of moderate-low density horse mussels within Kaipakirikiri Bay, next to Kumutoto Bay, inner-QCS (BT17-QC46) ; j-l) patchy beds of low density horse mussels within inner QCS: j) Kumutoto Bay (CB17-C29); k) Iwirua Point (MDC18-Q08); and l) Onahau Bay with several *Coscinasterias* (the main predator of horse mussels in the Sounds) on top of horse mussels (MDC18-Q96).

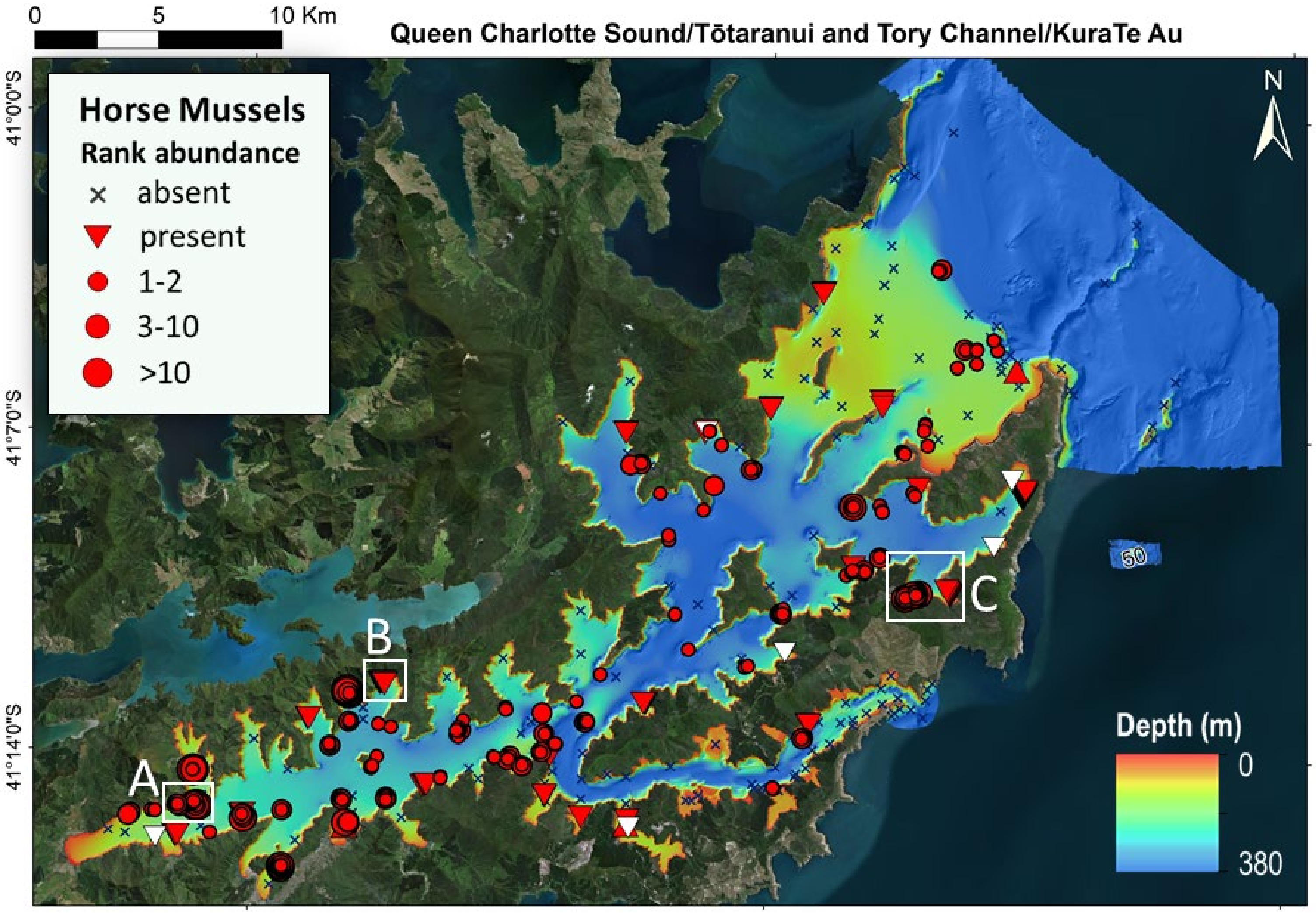


Figure 3-2: The distribution and rank abundance of horse mussels within QCS and TC. White triangles = horse mussels collected in BT17 beam trawls; inverted red triangles = presence in CB17 video-transects; upright red triangles = presence in HS51 dropcam video-footage. White boxes labelled A-C, are presented in zoomed in form in Figure 3-3. Counts = relative abundance ranks of absent (0), present (1-2), few (3-10), lots (>10 individuals) per 15 sec data records.

Table 3-2: Descriptions of horse mussel beds from the four recent video surveys (HS51; BT17, CB17 and MB18). Green shading = extensive or moderately dense beds (albeit ≤30% cover within any single data record); light-orange shading = low density beds; no shading = sparse bed or notable occurrences of horse mussels. Δ = CB17 presence of *Atrina* beds described from video footage; * *Atrina* bed described from video footage, but no *Atrina* collected in beam trawl; ^ extensive bed based on nearby sites also having extensive horse mussels. ESMS=Ecological Significant Marine Site (as defined in Davidson et al. 2011).

Area	Survey	Site	Location	Bed density	Horse mussel bed description
QCS Inner	BT17	QC46*	Kaipakirikiri Bay (alongshore)	Mod-low extensive	Video shows low to moderate density *Atrina* bed in 15-20 m water depth, with localised clusters of 3–7 *Atrina* per m^2. Bed extends alongshore for >300 m (and downslope for ~150 m based on MDC18-Q193 run downslope, perpendicular to this site). Video: Muddy-sand with some shell hash and covering of silts; Beam trawl catch incl. mixed red algae (dominated by *Gracilaria truncata*), mudworms, few encrusting sponges, some shell- and terrestrial plant debris. No *Atrina* collected in the beam trawl. Not an existing ESMS site.
QCS Inner	BT17	QC55	Takaputira Pt, Ngakutu Point	Patchy sparse-low extensive	Patchy sparse-low *Atrina* bed in 20–23 m depth, extending for ≥ 300 m. Silty muds with occasional shell debris, catch incl. green algae (*Codium fragile*), high densities of strawberry cockles (*Pratulum pulchellum*) and spotties (*Notolabrus celidotus*).
QCS Inner	BT17	QC60*	Picton (SE side of Bay, NE of ferry terminal)	Low-mod extensive	Patchy mostly low density *Atrina* bed in 13–16 m depth, extending for ~300 m along entire transect, with some moderately dense patches. Silty mud with burrows, catch incl. starfish (mostly *Patiriella*), patches of red algae (mostly *Stenogramma*) and some parchment worms. No *Atrina* collected in the beam trawl.
QCS Inner	CB17	C29Δ	Kumutoto Bay	Patchy sparse-low extensive	Extensive low density *Atrina* bed 10–23 m depth range (≥ 200 x 100 m in size, likely more extensive). Muddy-sand with shell-hash and some shell-debris, and brachiopods, 1x elephant egg-case. Two thirds of mussel bed along this transect lies within ESMS-4.15 [Sharks].
QCS Inner	CB17	C30Δ	Torea Bay (inner NW side)	Patchy low	Patchy low density *Atrina* bed on lower slope in 14–24 m depth (50 m distance up slope, unknown how far alongshore). Horse mussels recorded along lower edge and below *Galeolaria* zone. Bed includes a few juvenile *Atrina.*
QCS Inner	CB17	C31Δ	Iwirua Pt	Sparse-low	Sparse-low density *Atrina* bed in 22–27 m depth, extending 100 m across the sediment slope of the outer ridge. Muddy sediments, with scallops common, dense hydroids growing on some horse mussels. Part of historic bed described by Hay (1990) occurring between Iwirua Pt to Wedge Pt; Transect lay within ESMS-4.7.
QCS Inner	CB17	C32Δ	Ngakutu Point	Sparse-low	Sparse-low density *Atrina* bed in 11–17 m depth, extending across outer ridge ≥ 57 m down sediment bank, few juvenile *Atrina*, few scallops. Shell-debris sandy sediments, lots of elephant egg cases, trash including dumped car tyres. NE side of bed in Ngakuta Bay described by Hay (1990); Transect lies within ESMS-4.6.
QCS Inner	MDC18	Q08	Iwirua Pt	Sparse-low	Sparse-low density Atrina bed in 11-28 m depth, extending 200 m down sediment slope of ridge. NE side of bed in Ngakuta Bay described by Hay (1990). Transect lies partially within ESMS-4.7 and 4.8.

Area	Survey	Site	Location	Bed density	Horse mussel bed description
QCS Inner	MDC18	Q11	Bobs Bay, Picton	Patchy sparse/low	Patchy sparse-low density *Atrina* on sediment slope in 9–19 m depth, but many data records along the transect had no *Atrina*. Sediment change up slope denoted start of *Atrina* zone. Silty muds, few scallops, few brachiopods, patches of wireweed, few parchment worms. Several *Coscinasterias* starfish climbing/feeding on *Atrina*. *Bispira* bed in depths < 10.5 m.
QCS Inner	MDC18	Q193	Kaipakirikiri Bay (downslope)	Patchy low-mod extensive	Patchy but extensive *Atrina* bed mostly low density in 11-25 m depth (mean density of 1.03 *Atrina* per m^2), with localised clusters in ~21-23 m (4-6 *Atrina* per m^2). Bed extends downslope for ~150 m (and alongshore for >300 m based on BT17-QC46 beam tawl towed alongshore, perpendicular to this site). Bed contains some very large-sized *Atrina*, along with some juvenile *Atrina*. Site characterised by muddy-sands, frequent scallops, few brachiopods. Also, high proportion of broken *Atrina* shells or shells on sediment surface. Not an existing ESMS designation.
QCS Inner	MDC18	Q92	Houhou Point	sparse	Sparse *Atrina* on sediment slope (mean 0.47 *Atrina* per m^2) extending 38 m up slope, with some localised clusters (2-4 *Atrina* per m^2). Silty mud, with tracks and buried shell debris in places. Mostly adult *Atrina,* with a few juvenile *Atrina*.
QCS Inner	MDC18	Q95	Waikawa Hrbr	Patchy sparse	Very sparse and patchy *Atrina*. Silty mud with patches of mixed red algae (possibly *Gracilaria*).
QCS Inner	MDC18	Q96	Onahau Bay (sth side of bay)	Sparse/low	Sparse-low density *Atrina* bed in depths of 9–18 m (mean of 0.91 *Atrina* per m^2), extending 50 m up slope, with localised clusters in 13–15 m (3-8 *Atrina* per m^2). Silty sediments with shell-debris in places.
QCS Mid	BT17	QC25	Te Ipapakereru Bay	Patchy sparse-low extensive	Patchy sparse *Atrina* bed in depths of ~16-29 m, extending for ~400 m from the head of the bay, with some low-density zones in ~20 m depth. Some broken and whole-dislodged *Atrina* shells seen on the seabed. Muddy-sand with burrows, some patchy shell debris, and occasional small patches of wireweed. Subsequent catch including a few brachiopods (*M. sanguinea*), 1x *Atrina*, and newly settled blue cod.
QCS Mid	HS51	C24	Bay of Many Coves (inside entrance)	Patchy low	Patchy low-moderate density *Atrina* bed in 29 m depth. Muddy sediment with burrows and scallops (dropcam on seafloor for only 19 sec). No information on how extensive this bed is.
QCS Outer	BT17	QC14	Resolution Bay (near wharf)	Patch sparse	Patchy sparse *Atrina* bed, not very extensive (< ~50 m). Video: Sediments with thick layer of shell debris in places and patchy cover of mixed red algae (incl. *Rhodymenia* sp. and *Callophyllis angustifrons*). Beam-trawl catch incl. few brachiopods (*M. sanguinea*), newly settled and juvenile blue cod. Resolution Bay locally protected from fishing by lodge owners, who stated and were seen feeding fish daily off the wharf; but Bay is not officially protected.
QCS Outer	BT17	QC19	South of Otonga Pt Onauku Bay, East Bay (E)	Low/mod	Low-moderate density *Atrina* bed in 23–26 m depth, 328.5 m extent (est. mean ~1.6–2.1 *Atrina* per m^2), with localised clusters of ~3–7 *Atrina* per m^2. Muddy-sands, with a few urchins and starfish (*Coscinasterias*); catch incl. few brachiopods (*Neothyris lenticularis* and *Magasella sanguinea*), sponges (incl. *Crella incrustans*), and newly settled and juvenile blue cod. Not an existing ESMS.

Area	Survey	Site	Location	Bed density	Horse mussel bed description
QCS Outer	BT17	QC20	Matiere Point Otanerau Bay, East Bay (SW)	Patchy sparse-low extensive^	Patchy sparse to low density *Atrina* bed in 24 m depth, extending ~180 m along transect (also see nearby sites MDC18 Q27-Q28). Broken *Atrina* and whole shells on seabed. Muddy-sands, with red algae in places (mostly *Adamsiella angustifolia*), catch incl. high densities of red urchins, scallops, brachiopods (*N. lenticularis*), newly settled blue cod. *Beam trawl skirted the outside edge of ESMS-4.23.*
QCS Outer	BT17	QC21	Ruapara Bay, Onauku Bay, East Bay (NE)	Patchy sparse-low extensive^	Low density bed in 14-28 m depth, extending ~300 m on western side of the bay, but sparse occurrence within the moderately-dense red algae meadow (mostly *Gracilaria truncata*, 16–18 m depth). Video: silty-sediment; Beam-trawl catch incl. high densities of red urchins (in amongst the algal meadow), parchment worms (unident.) and juvenile blue cod. This bed occurs ~200 m west of the Ruapara-bed described by Hay (1990), and occurs within the western side of ESMS-4.24.
QCS Outer	CB17	C02$^{\Delta}$	Sth Anakakata Bay Duck Pond-west	Patchy sparse	Sparse numbers of adult and juvenile *Atrina* in 10-13 m depth, along edge of scoured channel feature. Shelly sediments with some bladed red algae.
QCS Outer	CB17	C04$^{\Delta}$	Long Island MR (NW side of Islands)	Low	Low density *Atrina* bed in 15–18 m depth (1.6 *Atrina* per m^2) on the NW side between Long Island and Kokomohua Island beyond the reefs, extending ≥57.6 m away from Islands, with common localised clusters of 3-6 *Atrina* per m^2. Coarse sediments, with newly settled juvenile blue cod. This is the same *Atrina* bed described by Haggitt (2017) within LIMR.
QCS Outer	CB17	C09$^{\Delta}$	Ruapara Bay, Onauku Bay, East Bay (NE)	Patchy low/mod Extensive^	Patchy, low-moderate density *Atrina* bed in 10–20 m depth on eastern side of the bay (mean 1.04 *Atrina* per m^2), with some of the highest localised densities in 13–16 m (max. 10 *Atrina* per m^2, with clusters of 5–9 *Atrina* per m^2 common). Muddy sands, with shell-debris and some cobbles; scallops common, few red urchins, few small patches of *Acromegalomma* tubeworms. This bed occurs ~500 m SE of the Ruapara *Atrina* bed described by Hay (1990), and lies within the eastern side of ESMS-4.24.
QCS Outer	CB17	C10$^{\Delta}$	Te Aroha Bay, Otanerau Bay, East Bay (SE)	Patchy low extensive	Patchy low density *Atrina* bed in 15–21 m depth (0.5 *Atrina* per m^2), extending ~200 km alongshore, with few clusters of 2–3 *Atrina* per m^2. Coarse grained sediment with some shell debris, patchy to moderately dense mixed red algae (poss. *Gracilaria truncata*) in 21 m depths, scallops common, 1x elephant egg case. Video transect runs across ESMS-4.21 and into 4.22, with *Atrina* bed mostly within ESMS-4.21, but also extends north of boundary towards ESMS-4.22.
QCS Outer	HS51	C47	Ruapara Bay, Onauku Bay, East Bay (NE)	Low extensive^	Low density *Atrina* bed in 28 m depth. Muddy-sand with shell hash, few brachiopods, small wireweed patches, some bladed red algae (dropcam for 29 sec). Site located ~100 m south of the Ruapara-bed described by Hay (1990); and lies inside the southern end of ESMS-4.24.
QCS Outer	MDC18	Q27	Puriri Bay, Otanerau Bay, East Bay (SW)	Patchy low extensive^	Patchy low density *Atrina* bed in 11-21 m depth (mean density of 1.41 *Atrina* per m^2), extending >160 m down gentle slope (also see nearby sites Q28, and BT17-QC20), with localised clusters along much of transect (3-5 *Atrina* per m^2). Muddy-sands with silt and biofilm and shell debris in places. Scallops common, parchment worms in some places, newly settled bluecod. Few *Coscinasterias* on horse mussels. Some *Atrina were dead but had* intact shells standing *in situ*, while some shells were intact on lying on the seafloor. This *Atrina* bed lies within, but also extended shallower beyond ESMS-4.23.

Area	Survey	Site	Location	Bed density	Horse mussel bed description
QCS Outer	MDC18	Q28	SW of Puriri Bay (East Bay)	Low Extensive^	Low density *Atrina* bed in 22-25 m depth, extending 238 m across the eastern side of the bay (also see nearby site Q27 and BT17-QC20), with localised clusters in ~21-23 m depth (3-6 *Atrina* per m^2). Muddy-sands with biofilm and siltveneer in places. Patchy red algae thickly covered in silt (eastern end of transect, 21-22 m depth), few brachiopods (*Neothyris lenticularis*), scallops, and red urchins. Some broken *Atrina* shells. Atrina bed within this transect lies within, but also extends deeper beyond ESMS-4.23.

Other notable sites:

- HS51-C10: Sediment basin, Inner QCS adjacent to Picton: site has a patch of horse mussel shell debris that includes dead *in situ* (i.e. upright) horse mussel shells, but no living horse mussels seen in the very short (25 sec) dropcam footage.
- MDC18-Q192: Video transect run within ESMS-7.4, which was originally delineated to protect a moderately-dense *Atrina* bed on inner duck pond, outer QCS). However, this bed appears to no longer exist (Davidson et al. 2015). In the current study, only 2 horse mussels and 2 records of *Atrina* shell-debris were recorded along this video-transect. This site was otherwise characterised by expansive muddy-sands covered in biofilm and silt with burrows.
- Beyond the study area: The 2017 Bottlenecks Beam trawl surveys included sites beyond the study area (out of scope of this study). However, unlike the study area which supported only low density horse mussel beds (≤30% cover), an expansive *Atrina* bed with moderately high densities (50-75% cover, with 17-34 *Atrina* per m^2) recorded on raised sediment bank at a site east of Chetwode Islands (latitude -40.9143, longitude 174.1258) in the Outer Sounds during the 2017 bottleneck beam trawl surveys (example photos provided in Appendix I), with 37 horse mussels collected having a mean shell length of 234.8 mm ± 40.7 SD (range 155-290 mm).

3.2.1 Preliminary correlation with HS51 data layers

Horse mussels were found in a wide range of sediment types from fine muddy-sands to coarse shell-debris covered in sediments, indicating that sediment composition alone is unlikely to be a reliable predictor of horse mussel occurrence or abundance. However, preliminary assessments of their distribution and abundance across both the survey-scale and at the scale of individual transects, relative to bathymetry, sediment composition and backscatter indicated that horse mussels are found in sediments with low-medium reflectivity, but this was conditional on these areas having a thicker layer of sediment in either a raised sill environment or on sediment slopes. Conversely, horse mussels were mostly absent in the extensive low-reflectivity (softer mud) *Amphiurid*-dominated sediment plains (these habitats are described in detail in Anderson et al. 2020a). The highest densities of horse mussels were recorded in sediment-sill habitats within East Bay – although bed densities were still relatively sparse to low %cover (<~5-25% cover), and Kaipakirikiri Bay (inner QCS) (details in Table 3-2). Zoomed in depth profiles of video-transects identified that horse mussels were present in almost all sediment-sill habitats throughout the Marlborough Sounds.

Sediment slopes within the study area that comprised moderately coarse sediments also frequently supported sparse to low densities of horse mussels. For example, two video transects (MDC18-Q92 and Q322) that surveyed either side of a raised bathymetric feature at Houhou Point (Grove Arm, Inner QCS[7]), showed that there was a clear demarcation between basin habitats (without horse mussels) and the sediment slope (with horse mussels) on either side of this feature, extending up to the very edges of the reef outcrop that limits their upper depth distribution.

Horse mussels, therefore, appear to occur on elevated sediments, either on sediment sills within embayments or on sediments slopes. This suggests that seafloor depth, slope, bottom reflectivity, and seafloor classification (based on backscatter and sediment sampling data) would be expected to be valuable predictors of horse mussel distributions. Based on these observations, a horse mussel zone (HMZ) can be approximately delineated for several video sites (e.g. Houhou Point, Kumutoto Bay, and Otanerau Bay) (Figure 3-3). This procedure indicated zones of likely horse mussel habitat surrounding the rocky-reef and shoreline at 1) Houhou Point, 2) encompassing much of the north-western bay within Kumutoto Bay and 3) much of the shallower parts of Otanerau Bay adjacent to the shoreline (Figure 3-3). In the HS modelling section below, we examine these bio-physical relationships formally and examine model outputs relative to this approximated HMZ and the video-observations from these three ESMS sites (Houhou Point, Kumutoto Bay, and Otanerau Bay).

[7] This raised feature is described in more detail in Anderson et al. 2020a (page 103; Figure **Error! Main Document Only.**).

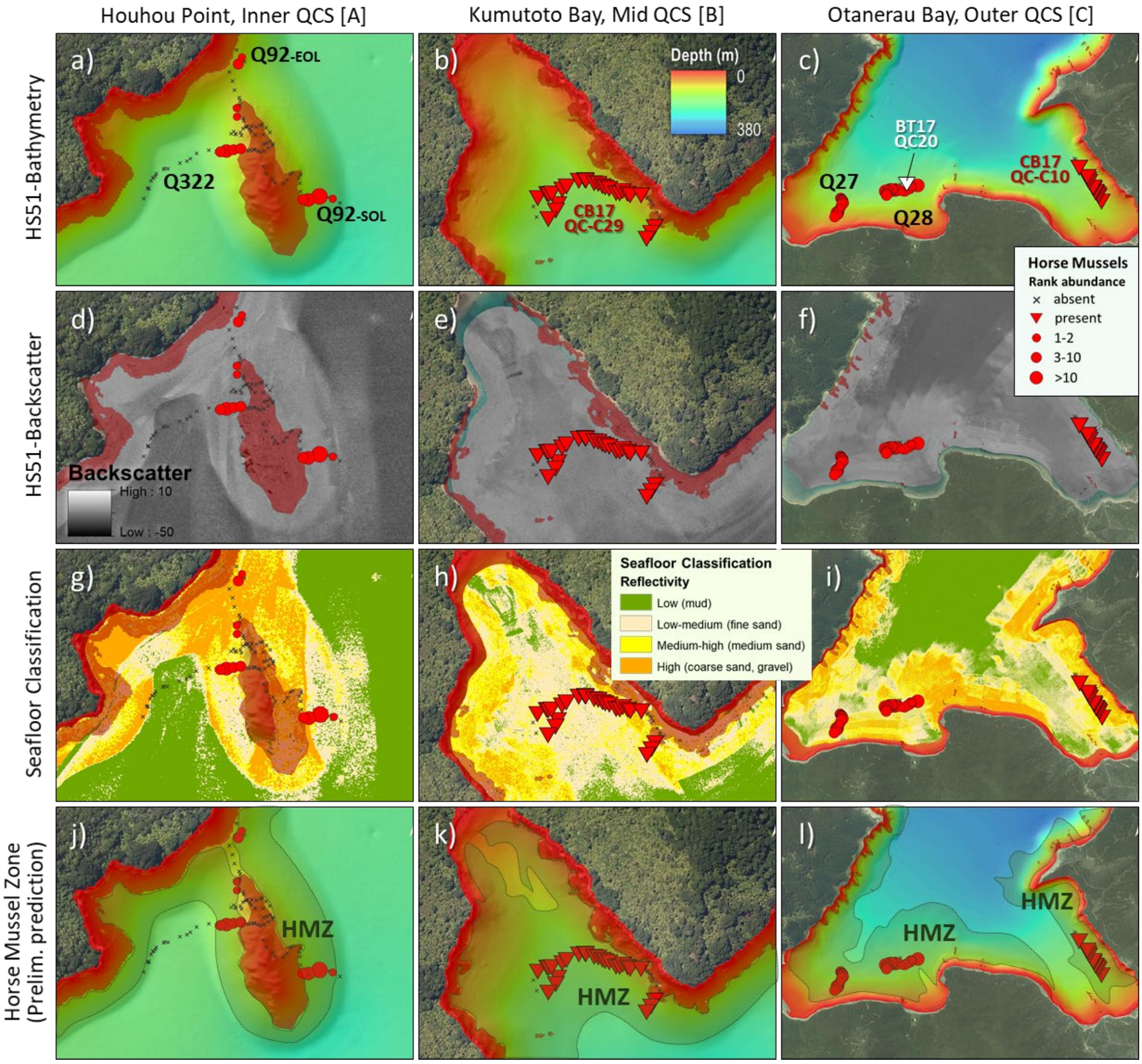


Figure 3-3: Distribution and rank abundance of horse mussels – overlaid on bathymetry, backscatter and seafloor classification – at three example sites within QCS. The locations of the three sites are shown as white boxes labelled A-C in Figure 3-1: Houhou Point subtidal reef [box-A] (left-plots), Kumutoto Bay [box-B] (central graphs), and Otanerau Bay [box-C] (right-graphs). Survey stations are labelled in plots a-c; for Q92-SOL = Start of line; EOL=End of line, to avoid confusion with video-transect Q322. In these plots, horse mussel distributions are overlaid on HS51 MBES data: a-c) Bathymetry (d-f), Backscatter, and (g-i) Seafloor classification – as derived from backscatter reflectivity relative to sediment grain size data (methods described in Neil et al. 2016b). The relationship between these layers was then used to depict areas where horse mussels are likely to occur – j-l) Shaded-green polygons = Predicted Horse Mussel Zones (HMZ). N.B.– these preliminary polygons are for exploration purposes only.

3.3 Habitat suitability modelling

3.3.1 Overall model performance

The separate components of the ensemble model described in Section 2.3.3 all performed well. The AUC values for the binomial component of both model types (Random Forest (RF) and Boosted Regression Trees (BRT) were above the rule-of-thumb value of 0.7 indicating "adequate" performance (Hosmer et al. 2013), with the BRT value above that of "excellent" performance (0.8). The R^2 values were very similar for the percent-cover component of each model type and these values indicate a very good fit to the data (Table 3-3).

There was general agreement between RF and BRT models in the relative order of importance of each explanatory variable (Table 3-4, Table 3-5). The most influential predictor variable in the ensemble models for both the presence absence and percent cover components of the overall hurdle model was the near-bottom current speed, indicating a general preference of horse mussels for sheltered embayments with low to moderate current speeds rather than more exposed environments with faster currents. Distance to the nearest headland was also an important predictor for the presence/absence models, but less so for the binomial models. Percent sand, slope, depth, and seafloor rugosity were all of moderate influence in both presence/absence and percent cover models. The Residual Autocorrelation variable (RAC) was strongly influential in the percent cover models but had only a minor influence in the presence/absence models. Thus, there is some spatial autocorrelation relating to patchiness of horse mussel densities (i.e., localised clumps) that is not being accounted for by the available predictor variables, and the RAC variable helps to account for this. The variables with the least influence in the models overall were distance to rock and curvature.

Table 3-3: Model performance for each component of the ensemble model. RF = Random Forest; BRT = Boosted Regression Trees.

Model component	Model performance	
	RF	BRT
Binomial (AUC)	0.70	0.91
Percent cover (R^2)	0.69	0.68

Table 3-4: Predictor influence in presence/absence component models. Mean percent influence from 100 bootstrap model runs, ordered from most to least influential variables overall.

Environmental variable	BRT	RF	Ensemble
Near-bottom current speed	24.9	17.9	21.4
Distance to headland	13.1	11.9	12.5
Percent sand	9.8	10.2	10.0
Slope	9.2	10.5	9.8
Seafloor rugosity (VRM)	9.4	10.2	9.8
Depth	9.5	9.9	9.7
Curvature	6.6	7.8	7.2
Slope standard deviation	5.5	8.6	7.0
Distance to rock	5.8	7.3	6.6
RAC	6.3	5.8	6.0

Table 3-5: Predictor influence in percent cover component models. Mean percent influence from 100 bootstrap model runs, ordered from most to least influential overall.

Environmental variable	BRT	RF	Ensemble
Near-bottom current speed	15.1	14.9	15.0
RAC	15.3	14.4	14.9
Seafloor rugosity (VRM)	11.8	11.6	11.7
Slope	10.5	10.3	10.4
Depth	10.6	9.6	10.1
Slope standard deviation	7.7	9.3	8.5
Distance to headland	8.3	8.3	8.3
Percent sand	8.3	8.2	8.2
Curvature	7.0	6.1	6.6
Distance to rock	5.4	7.3	6.4

3.3.2 Predicted distributions of horse mussels

The ensemble model predictions of horse mussel densities (percent cover) show a strong association with the innermost areas of the multitude of bays and inlets within the study area. Areas of relatively high densities (percent cover over about 0.8) in QCS include Onauku and Otanerau Bays within the larger East Bay area of the outer QCS, the northern parts of Endeavour Inlet and, in the west, Picton Harbour, Waikawa Bay, and the southern and western bays of Grove Arm (Figure 3-4, Figure 3-5, Figure 3-6, Figure 3-7). The high densities in Otanerau Bay are well supported by the observational data and within this area overlap with existing ESMS sites in Te Aroha Bay (ESMS 4.21 [algae]), Puriri Bay (ESMS 4.22 [invertebrates]), and Matiere Point (ESMS 4.23 [invertebrate]). The high densities in Onauku Bay are also supported by the observations and overlap with invertebrate ESMS sites 4.24 and 4.25 (Figure 3-5, Figure 3-9). In Grove Arm, areas of higher horse mussel densities overlap with the western end of Bottle Bay ESMS site 4.3 [physical] and with ESMS site 4.6 at Ngakuta Point [algae] (Figure 3-7).

Areas within TC with high predicted densities comprise mainly the bays on the south side of the channel, especially Maraetai, Onapua, and Oyster Bays, but also some small parts of Kawhia and Deep Bays on the northern side (Figure 3-8). The ensemble model predicts horse mussels to be absent or in very low densities throughout much of the deeper channels and wider parts of the study area, as well as the outer parts of most of the large embayments. Notably, there are very few areas of high density in the northern part of the outer QCS, and little overlap of higher horse mussel densities with ESMS sites.

Predicted distributions align well with observational data in Otanerau and Onauku Bays, where some of the largest areas of high predicted and observed density exist, with generally low uncertainty (CVs) in areas with high predicted density, and vice versa. The models predict a degree of patchiness in horse mussel densities in these areas, which aligns well with historical observations. At Houhou Point in the inner QCS there were many absences recorded in the video transects, but where there were positive values predictions aligned well with observations, showing patchy areas of high densities at locations where horse mussels were observed, within ESMS 4.3 at Houhou Point [algae]. Uncertainty was again correlated with predicted abundance here, with areas of high abundance associated with low uncertainty. Sampling in northeastern Kumutoto Bay also aligned well with predictions, with patches of denser beds indicated for several areas in this bay, overlapping strongly with ESMS site 4.15 [shark] (Figure 3-9).

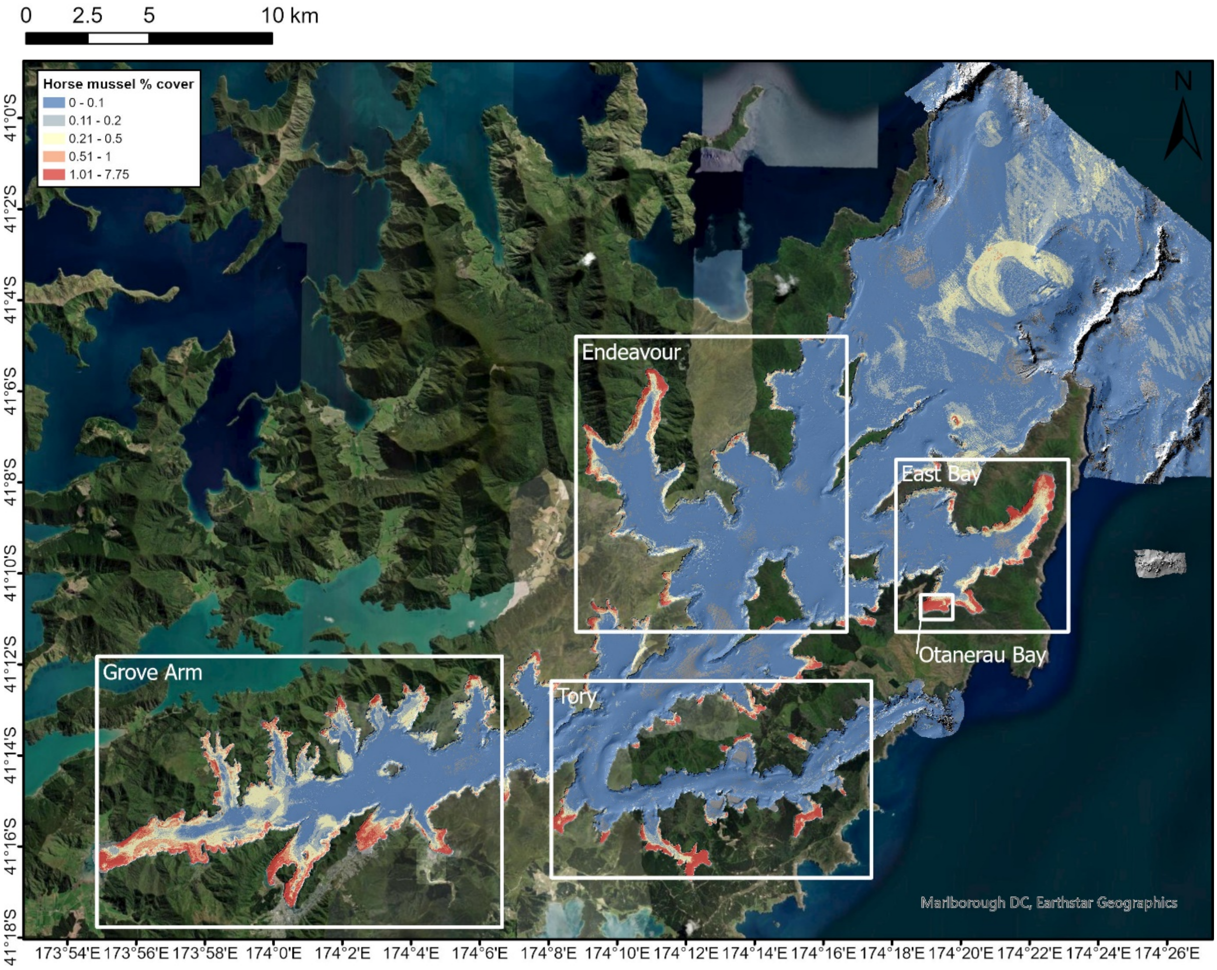


Figure 3-4: Predicted distribution of horse mussels (*Atrina zelandica*) across the HS51 survey area of QCS and TC. Graduated colours (from blue to red - see scale-bar) indicate the predicted percent cover, overlaid on a hill-shade bathymetry relief. See Figures 3-5 to 3-9 for detail within the four white boxes.

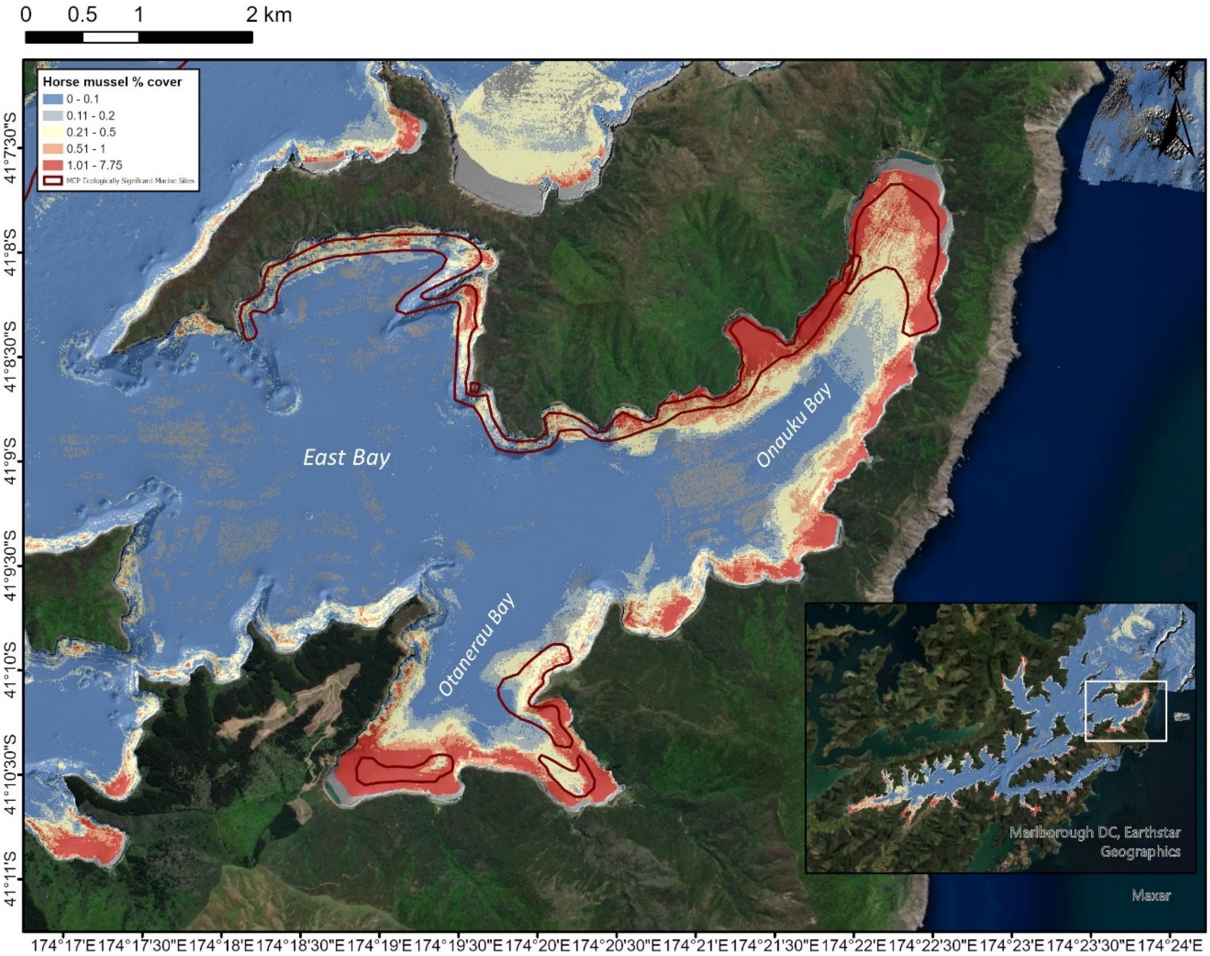


Figure 3-5: Predicted distribution of horse mussels (*Atrina zelandica*) within the East Bay area of outer QCS. Graduated colours (blue to red) indicate the predicted percent cover, overlaid on a hill-shade bathymetry relief. Existing Ecologically Significant Marine Sites (ESMS) shown as red polygons.

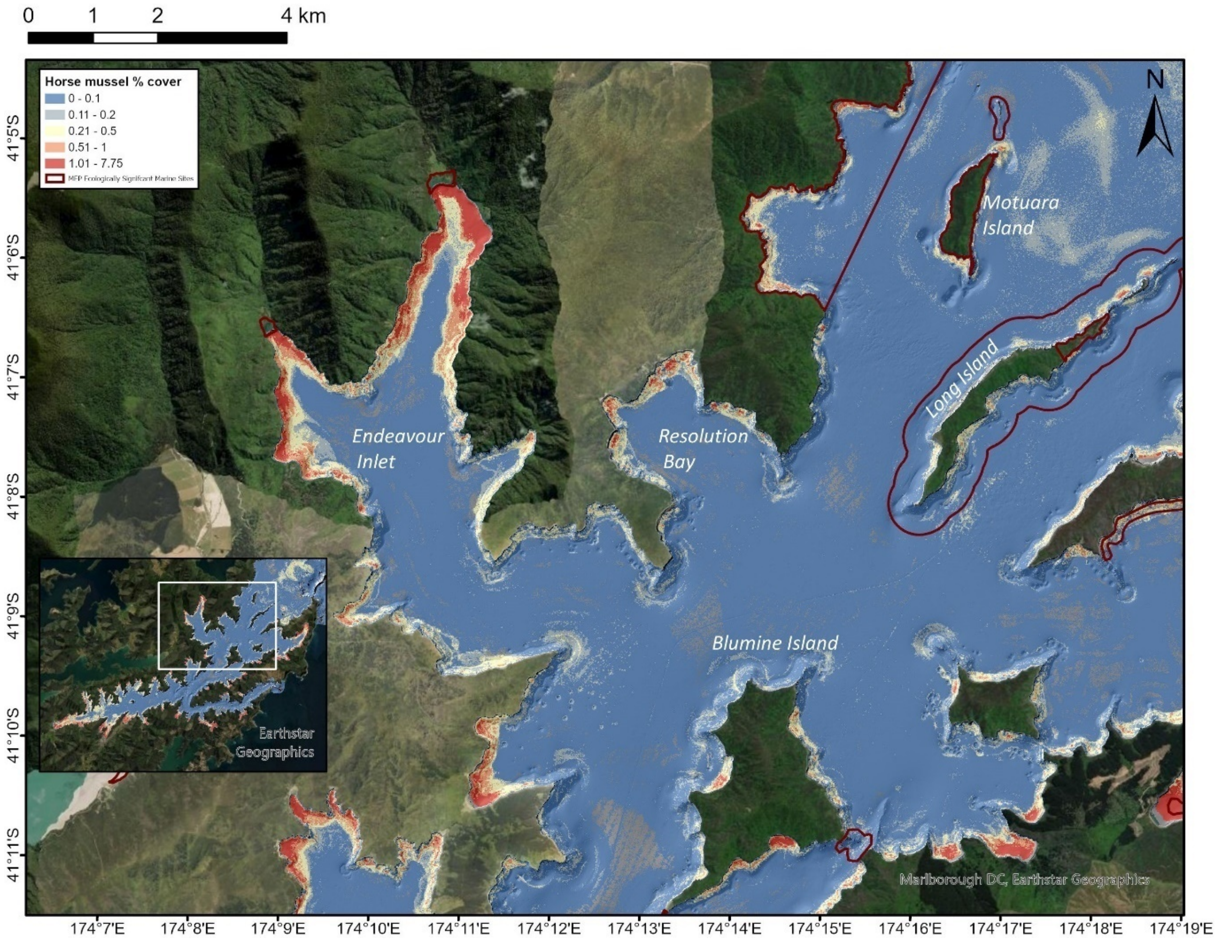


Figure 3-6: Predicted distribution of horse mussels (*Atrina zelandica*) within the Endeavour area of outer QCS. Graduated colours (blue to red) indicate the predicted percent cover, overlaid on a hill-shade bathymetry relief. Existing Ecologically Significant Marine Sites (ESMS) shown as red polygons.

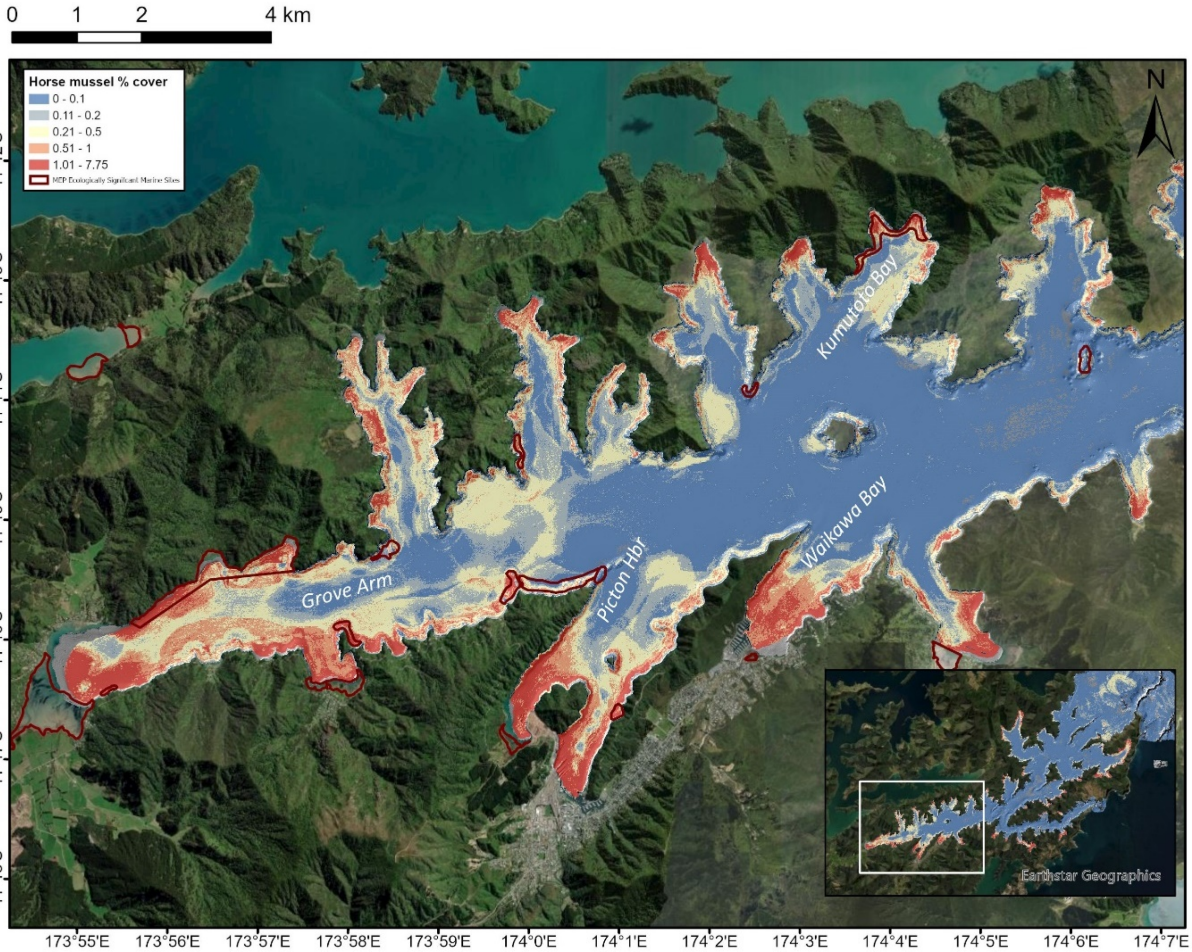


Figure 3-7: Predicted distribution of horse mussels (*Atrina zelandica*) within the Grove Arm area of inner QCS. Graduated colours (blue to red) indicate the predicted percent cover, overlaid on a hill-shade bathymetry relief. Existing Ecologically Significant Marine Sites (ESMS) shown as red polygons.

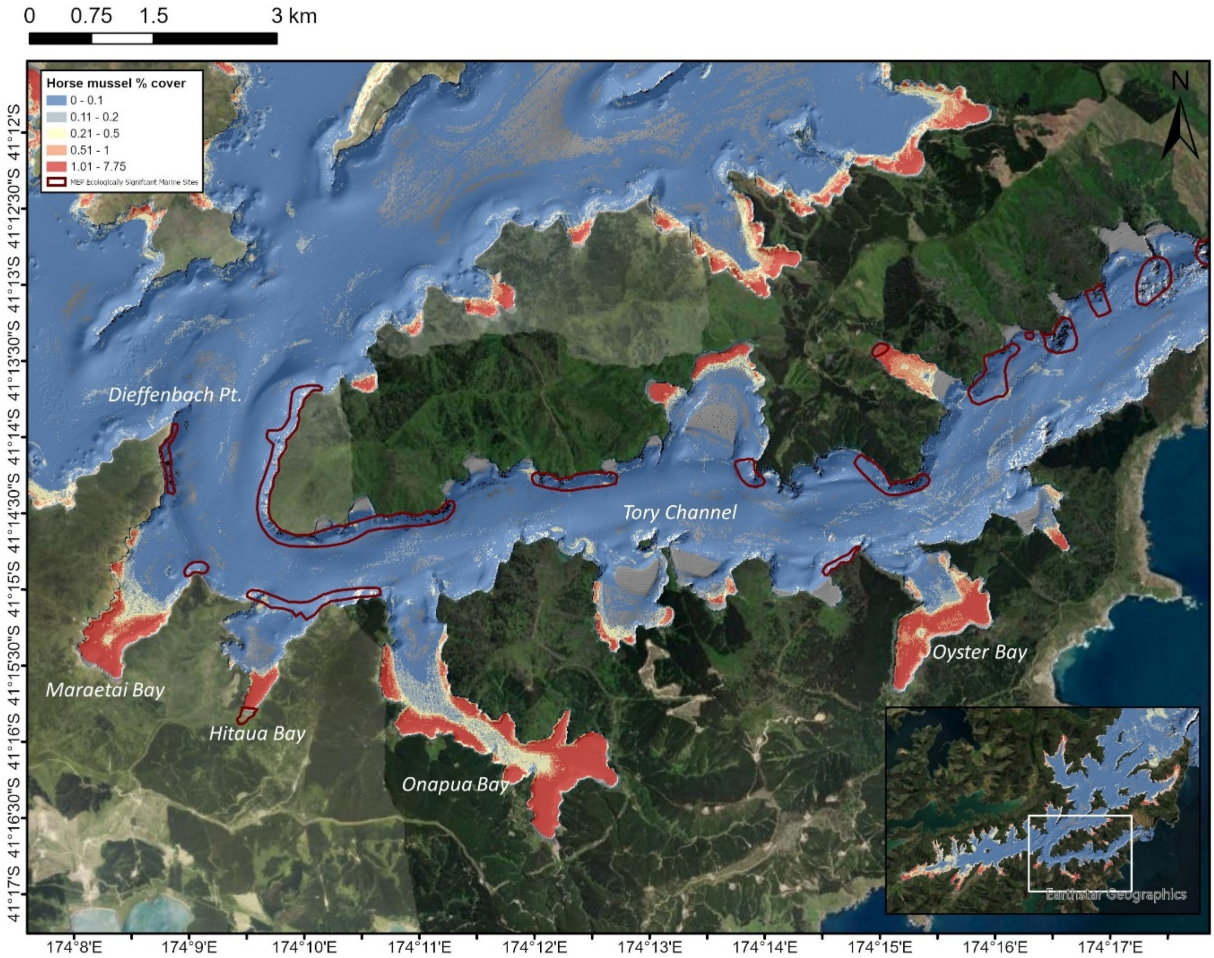


Figure 3-8: Predicted distribution of horse mussels (*Atrina zelandica*) within Tory Channel. Graduated colours (blue to red) indicate the predicted percent cover, overlaid on a hill-shade bathymetry relief. Existing Ecologically Significant Marine Sites (ESMS) shown as red polygons.

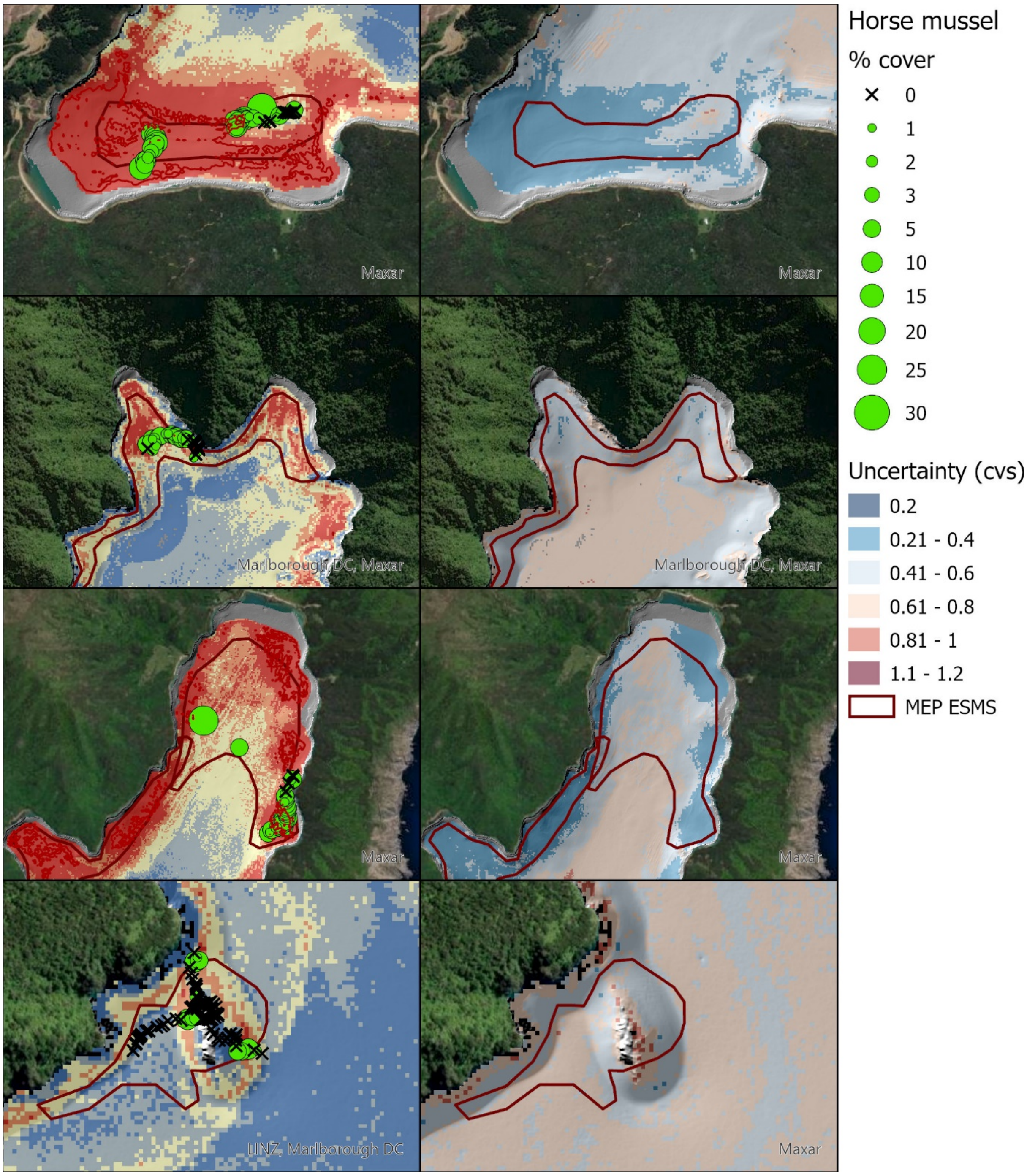


Figure 3-9: Predicted densities of horse mussels (*Atrina zelandica*) at selected locations in QCS and TC. From top to bottom; Otanerau Bay; Kumutoto Bay; Onauku Bay; Houhou Point. Left figures, predicted percent cover; right figures, precision or uncertainty of predicted distributions (CVs, presented as a fraction). Green circles = observed horse mussel % cover, black crosses = absences. Contours are added to the predicted percent cover figures at a threshold of 3% (red lines). All figures are overlaid on MBES bathymetry. Existing Ecologically Significant Marine Sites (ESMS) shown as red polygons.

4 Discussion/summary

The recent comprehensive bathymetric mapping of the seafloor in Queen Charlotte Sound, Tory Channel, and adjacent areas of Cook Strait (Neil et al. 2018a,b), and the subsequent and extensive biological sampling coverage using high-resolution state-of-the-art underwater video technology (as described in Anderson et al. 2020a), has enabled the development of predictive models that can provide detailed spatial information on the potential distribution of benthic fauna within the south-eastern section of the Marlborough Sounds, and aid management decisions. Earlier sampling surveys relied on scuba divers that were restricted to less than about 20 m water depth and often only provided presence information and site-descriptions, whereas the video data provides highly accurate abundance information. In addition, crucially for models that attempt to predict species abundance rather than simply a relative measure of habitat suitability, accurate absence information can be extracted from the high-quality image data available from advanced underwater camera systems.

In this study, we applied sophisticated species distribution modelling methods to predict densities of a key biogenic habitat species in the Marlborough Sounds, the horse mussel (*Atrina zelandica*). Environmental predictors, based on a combination of high-resolution bathymetric data (and derivatives), seabed current modelling, and a model-specific variable to adjust for the effects of spatial autocorrelation, were successfully combined with abundance data from the camera surveys to produce models estimating potential horse mussel densities with an acceptable degree of reliability, as measured by model performance metrics and estimates of precision.

The key environmental variables in the habitat suitability modelling documented in this report were found to be bottom current speed and distance to the nearest headland, with percent sand, and seabed slope, depth, and rugosity also variously influential in the component models that were combined to form the final ensemble model. The maps supplied along with this report can be used to approximately delineate areas most likely to contain high densities of horse mussels by applying a threshold value to the predicted values of percent cover. In this report we have used values of over 0.8% to approximate areas of higher density, and contours at a value of 3% are shown for Otanerau and Onauku Bays in Figure 3-9. However, any value can be used depending on the objective of the illustration and MDC's management aims.

The predicted percent cover did not exceed 7.8% at any location within the modelled area. Further, neither the predicted horse mussel percent cover nor any observed values of percent cover from the camera survey sites, exceeded the level of "*30% cover, over an area of 100 m^2 or more*" required for a bed of large bivalve molluscs to be designated a "sensitive environment" for the purposes of Schedule 6 of the EEZ Permitted Activities Regulations 2013, a designation based on MacDiarmid et al. (2013).

Areas identified by both observations and model predictions to have the highest densities of horse mussels include Otanerau and Onauku Bays within East Bay, as well as Grove Arm in the inner QCS. These locations were noted as having high densities in surveys from the 1980s to 2010s (e.g., Hay 1990, Davidson et al. 2010b, Morrisey et al. 2019). The lower density beds identified by Hay (1990) and Haggitt (2017) towards the northwest entrance to QCS were not well supported by the sample data (although horse mussels were found, in low numbers, in this area) or the model predictions, confirming the decline in the populations in this area reported in Davidson et al. (2015). The reports of horse mussel presences in other locations, e.g., the bays along TC and in the Bay of Many Coves (Davidson et al. 2011; NIWA, unpublished data) were also supported by the models, but abundance data that might confirm the high predicted densities in some of these TC bays (Onapua and Oyster Bays in particular) does not exist. Several areas predicted to have relatively high densities of horse mussels overlapped with existing Ecologically Significant Marine Sites in the area, notably in East Bay (ESMS sites 4.21, 4.22, 4.23, 4.24, and 4.25), and in Grove Arm (ESMS sites 4.3 and 4.6).

This predictive model, like any model, will not always be correct and depending on the various inputs will in some areas even appear to conflict somewhat with observations. In addition, when predicting into unsampled areas the model is not able to take into account reduction in horse mussel densities due to damage from historical fishing operations and other damaging activities. It is important therefore, especially when considering localised distributions of horse mussels, to examine real observations (which are almost without error) alongside the predicted distributions. Historical observations (prior to the video surveys) should be treated with more caution, however, due to likely changes in distributions caused by the accumulation of anthropogenic effects and natural influences over time.

A recent study of filter-feeder communities in QCS/TC used HS51 bathymetry predictors and data from the MDC18 ground-truthing survey, along with other data not used in the current analysis, in a presence only modelling method (Maxent, Phillips et al. 2006), to produce a habitat suitability map for horse mussels across the same spatial extent as in the current study (Ribo et al. 2021). Although Maxent models predict only relative habitat suitability, as absence data aren't included, they are useful for predicting the relative likelihood of horse mussel occurrence. Their model broadly agrees with those of the current study in most areas, with the highest predicted suitability generally focused on the inner parts of the large bays and away from the deeper channels, and shows similar patterns in key areas such as East Bay and Grove Arm. However, the Ribo et al. (2021) model predicts relatively high suitability across outer QCS and TC, notably along the northwest coast of Arapaoa Island, that is not supported by the density estimates for these areas in the current study.

There were several areas within the study area where the modelling indicated high densities of horse mussels may be present, but no sample data exist to support these predictions (e.g., Oyster Bay and Onapua Bays in Tory Channel). A useful next step would be to ground-truth these locations (and locations predicted to have high densities of *Galeolaria* and bryozoans, Anderson et al. 2020c) by undertaking additional video-transect sampling, particularly at any locations that may be under consideration for some form of spatial management or protection in MDC's pMEP.

There also remains potential for predicting distributions of other taxa for which sufficient data exist from video surveys (e.g. giant lampshells, dog cockles (live and dead), *Amphiura correcta* ophiuroids), as the predictor layers and modelling techniques are well established. However, newly-developed analytical methods that simultaneously consider distributional data of multiple species as well as information on phylogenetic relationships, functional traits, and the spatio-temporal context in which the data were collected, may be a useful way to produce improved predictions of individual species distributions. These techniques also support community-level models that may help to ascertain the most important areas for consideration of specific management initiatives. One such method in use at NIWA is Joint Species Distribution Modelling (JSDM, Ovaskainen et al. 2017), with fully developed documentation now accessible for general application (Ovaskainen & Abrego 2020).

5 Acknowledgements

We wish to thank Juliet Milne (NIWA) for her useful review of a draft of this report. This project was funded by the Marlborough District Council.

6 References

Anderson, O., Stephenson, F., Behrens, E. (2020b) Updated habitat suitability modelling for protected corals in New Zealand waters. *NIWA Client Report* 2020174WN. Prepared for the New Zealand Department of Conservation, Wellington: 103.

Anderson, T., Anderson, O., Stephenson, F., Wadhwa, S. (2020c) Habitat suitability modelling of bryozoan and *Galeolaria* mounds within the HS51 survey area. *NIWA Client Report* 2020308WN. Prepared for Marlborough District Council: 38.

Anderson, T.J., Morrison, M., MacDiarmid, A., D'Archino, R., Nelson, W., Tracey, D., Clark, M., Gordon, D., Read, G., Morrisey, D., Kettles, H., Wood, A., Anderson, O., Smith, A.M., Page, M., Paul-Burke, K., Schnabel, K., Wadhwa, S. (2019) Review of New Zealand's Key Biogenic Habitats. *NIWA Client Report* 2018139WN. Prepared for the Ministry for the Environment: 184.

Anderson, T.J., Stewart, R., D'Archino, R., Stead, J., Eton, N. (2020a) Life on the seafloor in Queen Charlotte Sound, Tory Channel and adjacent Cook Strait. *NIWA Client Report* 2019081WN. Prepared for Marlborough District Council: 336.

Breiman, L. (2001) Random forests. *Machine learning,* 45(1): 5-32.

Clark, D., Taylor, D., Keeley, N., Dunmore, R., Forrest, R., Goodwin, E. (2011) Assessment of effects of farming salmon at Ruaomoko, Queen Charlotte Sound: deposition and benthic effects. Prepared for the New Zealand King Salmon Company Limited. *Cawthron Report*, 1992: 59.

Crase, B., Liedloff, A.C., Wintle, B.A. (2012) A new method for dealing with residual spatial autocorrelation in species distribution models. *Ecography,* 35(10): 879-88.

Cummings, V.J., Thrush, S.F., Hewitt, J.E., Turner, S.J. (1998) The influence of the pinnid bivalve *Atrina zelandica* (Gray) on benthic macroinvertebrate communities in soft-sediment habitats. *Journal of Experimental Marine Biology and Ecology,* 228(2): 227-240.

Davidson, R.J., Duffy, C.A.J., Gaze, P., Baxter, A., Du Fresne, S., Courtney, S., Hamill, P. (2010a) *Ecologically significant marine sites in Marlborough, New Zealand*. Co-ordinated by Davidson Environmental Limited for Marlborough District Council and Department of Conservation.

Davidson, R.J., Pande, A. (2002) Biological report on the benthos under and adjacent to a relocated mussel farm site located in East Bay. Prepared by Davidson Environmental Limited for Marlborough District Council. S*urvey and Monitoring Report,* 419.

Davidson, R.J., Baxter, A.S., Duffy, C.A.J., Gaze, P., du Fresne, S., Courtney, S., Brosnan, B. (2015) Reassessment of selected significant marine sites (2014-2015) and evaluation of protection requirements for significant sites with benthic values. Prepared by Davidson Environmental Limited for Marlborough District Council and Department of Conservation. *Survey and monitoring report*, 824.

Davidson, R.J., Duffy, C.A.J., Gaze, P., Baxter, A., du Fresne, S., Courtney, S., Hamill, P. (2011) *Ecologically significant marine sites in Marlborough, New Zealand*. Report co-ordinated by Davidson Environmental Limited, for Marlborough District Council and Department of Conservation. Published by Marlborough District Council: 172.

Davidson, R.J., Richards, L.A. (2015) Significant marine site survey and monitoring programme: Summary 2014 - 2015. Prepared by Davidson Environmental Limited for Marlborough District Council. *Survey and monitoring report*, 819.

Davidson, R.J., Richards, L.A., Duffy, C.A.J., Kerr, V., Freeman, D., D'Archino, R., Read, G.B., Abel, W. (2010b) Location and biological attributes of biogenic habitats located on soft substrata in the Marlborough Sounds. Prepared by Davidson Environmental Ltd. for Department of Conservation and Marlborough District Council. *Survey and monitoring report*, 575.

Elith, J., Leathwick, J.R., Hastie, T. (2008) A working guide to boosted regression trees. *Journal of Animal Ecology*, 77(4): 802-13.

Elvines, D., McGrath, E., Smeaton, M., Morrisey, D. (2019) Assessment of seabed effects from an open ocean salmon farm proposal in the Marlborough coastal area. Prepared for The New Zealand King Salmon Co. Limited. *Cawthron Report*, 3317: 63, plus appendices.

Fisheries New Zealand (2019) Temporary Closure of the Southern Scallop (SCA 7) Fishery. *Fisheries New Zealand Information Paper*, 2019/08. ISBN No: 978-1-99-000877-1 (online); ISSN No: 2624-0246 (online)

Georgian, S.E., Anderson, O.F., Rowden, A.A. (2019) Ensemble habitat suitability modeling of vulnerable marine ecosystem indicator taxa to inform deep-sea fisheries management in the South Pacific Ocean. *Fisheries Research*, 211: 256-274.

Hadfield, M. (2015) An assessment of potential for resuspension of fine sediments in Marlborough Sounds. Report prepared for Marlborough District Council. *NIWA Client Report* WLG2015: 53.

Hadfield, M., Broekhuizen, N., Plew, D. (2014) A biophysical model for the Marlborough Sounds. Part 1: Queen Charlotte Sound and Tory Channel. *NIWA Client Report* CHC2014116, prepared for Marlborough District Council: 183.

Haggitt, T. (2017) Long Island - Kokomohua Marine Reserve Habitat Mapping. A report prepared for the Department of Conservation, DOC-2748890, April 2017: 34.

Hay, C.H. (1990) The ecological importance of the horse mussel (*Atrina zelandica*) with special reference to the Marlborough Sounds. Prepared for Nelson/Marlborough Regional Office, DOC: 7.

Hewitt, J., Thrush, S., Gibbs, M., Lohrer, D., Norkko, A. (2006) Indirect effects of *Atrina zelandica* on water column nitrogen and oxygen fluxes: The role of benthic macrofauna and microphytes. *Journal of Experimental Marine Biology and Ecology*, 330(1): 261-273.

Hewitt, J.E., Pilditch, C.A. (2004) Short-term feeding responses of *Atrina zelandica* to suspended sediment concentrations: effects of environmental history and physiological state. *Journal of Experimental Marine Biology and Ecology,* 306: 95-112.

Hosmer, D.W.J., Lemeshow, S., Sturdivant, R.X. (2013) *Applied Logistic Regression, Third Edition*. John Wiley and Sons: 528.

Lohrer, A.M., Thrush, S.F., Lundquist, C.J., Vopel, K., Hewitt, J.E., Nicholls, P.E. (2006) Deposition of terrigenous sediment on subtidal marine macrobenthos: response of two contrasting community types. *Marine Ecology Progress Series,* 307: 115-125.

Lohrer, A.M., Chiaroni, L.D., Thrush, S.F., Hewitt, J.E. (2010) Isolated and interactive effects of two key species on ecosystem function and trophic linkages in New Zealand soft-sediment habitats. *New Zealand Aquatic Environment and Biodiversity Report,* 44: 69.

MacDiarmid, A.B., Bowden, D.A., Cummings, V., Morrison, M., Jones, E., Kelly, M., Neil, H., Nelson, W., Rowden, A.R. (2013) Sensitive Marine Benthic Habitats Defined. *NIWA Client Report* WLG2013-18. Prepared for the Ministry for Environment: 72.

McKnight, D.G., Grange, K.R. (1991) Macrobenthos-Sediment-Depth Relationships in Marlborough Sounds. *DSIR Marine and Freshwater Report*, P692. Prepared for the Department of Conservation: 1-19.

Morrisey, D., Berthelsen, A. (2016) Assessment of environmental effects of Waitohi Wharf capital dredging proposal. Prepared for Port Marlborough New Zealand Ltd. *Cawthron Report,* 2915: 19, plus appendices.

Morrisey, D., Fletcher, L. (2019) Biology and ecology of horse mussels (*Atrina zelandica*) with reference to the outer Marlborough Sounds area. Prepared for The New Zealand King Salmon Co Ltd. *Cawthron Report*, 3407: 40.

Morrison, M.A., Jones, E., Consalvey, M., Berkenbusch, K. (2014) Linking marine fisheries species to biogenic habitats in New Zealand: A review and synthesis of knowledge. *New Zealand Aquatic Environment and Biodiversity Report,* 130.

Neil, H., Mackay, K., Wilcox, S., Kane, T., Lamarche, G., Wallen, B., Orpin, A., Steinmetz, T., Pallentin, A. (2018a) Queen Charlotte Sound / Tōtaranui and Tory Channel / Kura Te Au (HS51) survey: What lies beneath? Guide to survey results and graphical portfolio. Part 1. *NIWA Client Report* 2018085WN: 229.

Neil, H., Mackay, K., Wilcox, S., Kane, T., Lamarche, G., Wallen, B., Orpin, A., Steinmetz, T., Pallentin, A. (2018b) Queen Charlotte Sound / Tōtaranui and Tory Channel / Kura Te Au (HS51) survey: What lies beneath? Guide to survey results and graphical portfolio. Part 2. *NIWA Client Report* 2018085WN: 118.

Norkko, A., Hewitt, J.E., Thrush, S.F., Funnell, G.A. (2006) Conditional outcomes of facilitation by a habitat-modifying subtidal bivalve. *Ecology*, 87: 226-234.

Norkko, A., Hewitt, J.E., Thrush, S.F., Funnell, G.A. (2001) Benthic-pelagic coupling and suspension-feeding bivalves: linking site-specific sediment flux and biodeposition to benthic community structure. *Limnology and Oceanography,* 46: 2067–2072.

Ovaskainen, O., Abrego, N. (2020) *Joint Species Distribution Modelling: With Applications in R. Ecology, Biodiversity and Conservation*. Cambridge University Press, Cambridge: 372.

Ovaskainen, O., Tikhonov, G., Norberg, A., Blanchet, F.G., Duan, L., Dunson, D., Abrego, N. (2017) How to make more out of community data? A conceptual framework and its implementation as models and software. *Ecology Letters,* 20(5): 561-576. <http://dx.doi.org/10.1111/ele.12757>

Phillips, S.J., Anderson, R.P., Schapire, R.E., (2006) Maximum entropy modelling of species geographic distributions. *Ecol. Model.,* 190: 231e259.

Ribo, M., Macdonald, H., Watson, S.J., Hillman, J.R., Strachan, L.J., Thrush, S.F., Mountjoy, J.J., Hadfield, M.G., Lamarche, G. (2021) Predicting habitat suitability of filter-feeder communities in a shallow marine environment, New Zealand. *Marine Environmental Research,* 163: 105218

Rowden, A.A., Anderson, O.F., Georgian, S.E., Bowden, D.A., Clark, M.R., Pallentin, A., Miller, A. (2017) High-resolution habitat suitability models for the conservation and management of vulnerable marine ecosystems on the Louisville Seamount Chain, South Pacific Ocean. *Frontiers in Marine Science*, 4: 335. doi: 10.3389/fmars.2017.00335.

Thrush, S.F., Dayton, P.K. (2002) Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity. *Annual Review of Ecology and Systematics*, 33: 449-473.

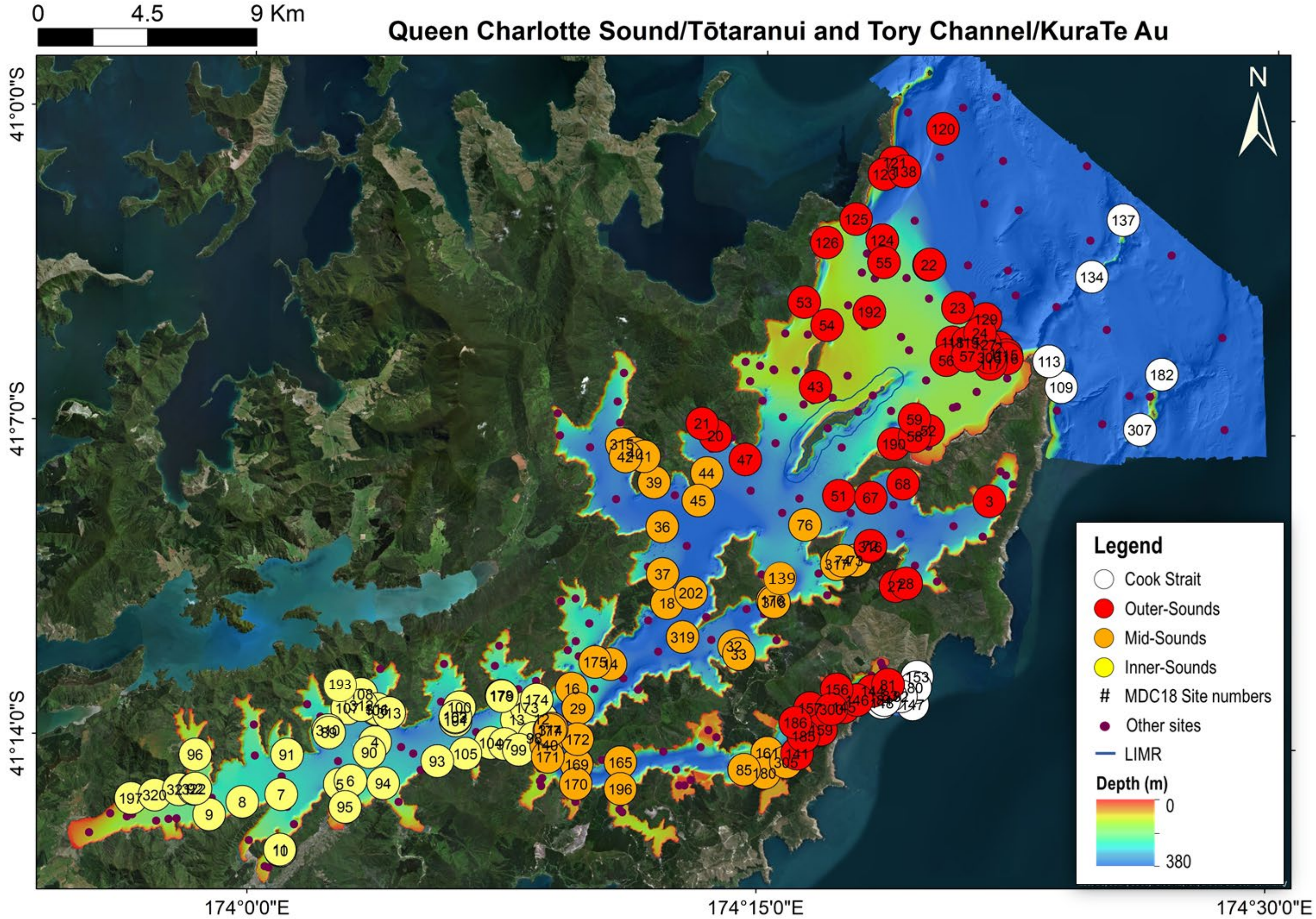
Turner, S.J., Hewitt, J.E., Wilkinson, M.R., Morrisey, D.J., Thrush, S.F., Cummings, V.J., Funnell, G. (1999) Seagrass patches and landscapes: the influence of wind-wave dynamics and hierarchical arrangements of spatial structure on macrofaunal seagrass communities. *Estuaries,* 22(4): 1016–1032.

Vooren, C.M. (1975) Nursery grounds of tarakihi (Teleostei: Cheilodactylidae) around New Zealand. *New Zealand Journal of Marine and Freshwater Research,* 9(2): 121-158.

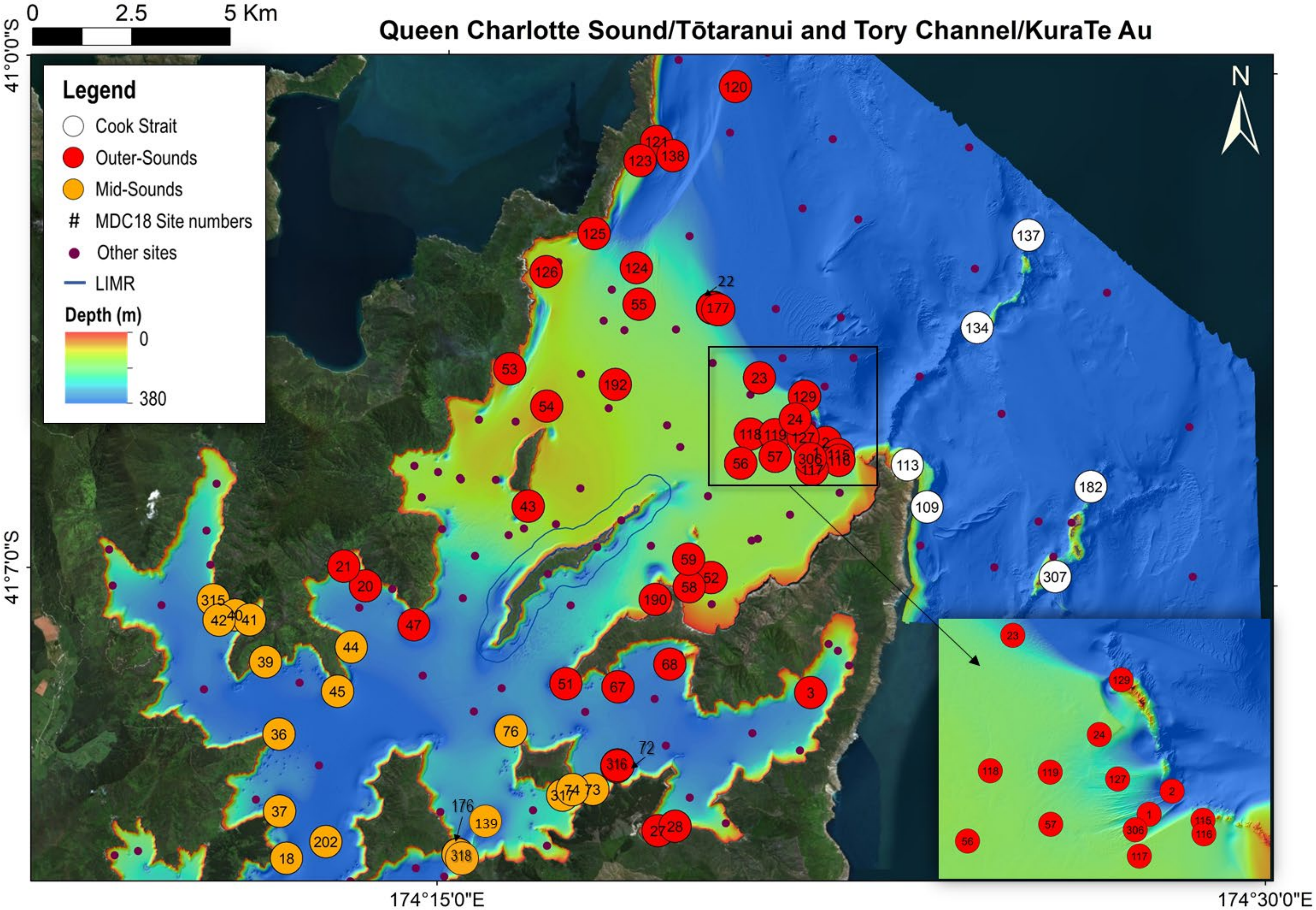
Warton, D.I., Hui, K.C. (2011) The arcsine is asinine: the analysis of proportions in ecology. *Ecology,* 92(1): 3–10.

Appendix A Map of MDC18 site locations (*see zoomed-in maps in Appendices B-D*).

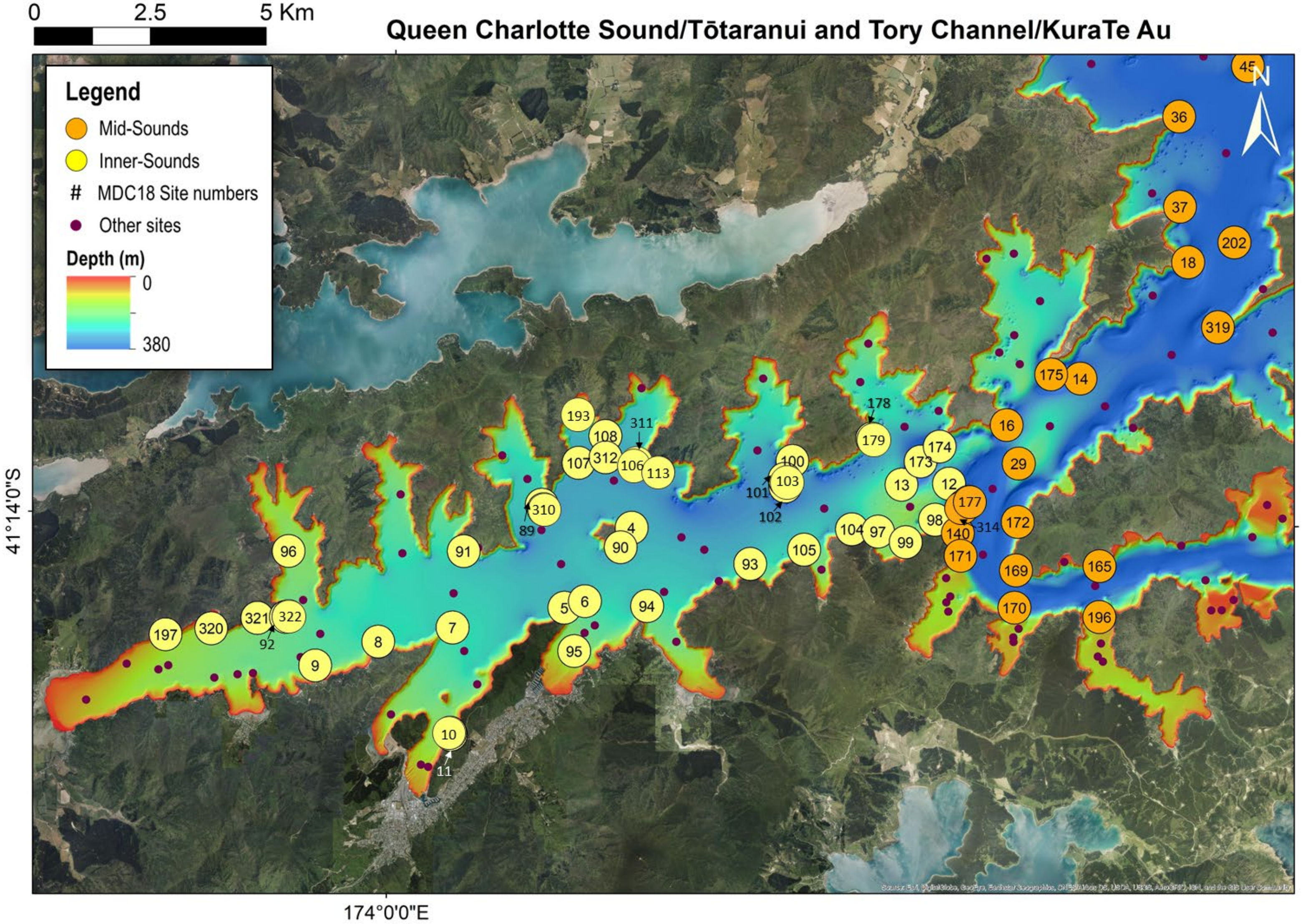
NB: Site maps presented in Appendices A-G are sourced from Appendices A-G in Anderson et al. (2020a).



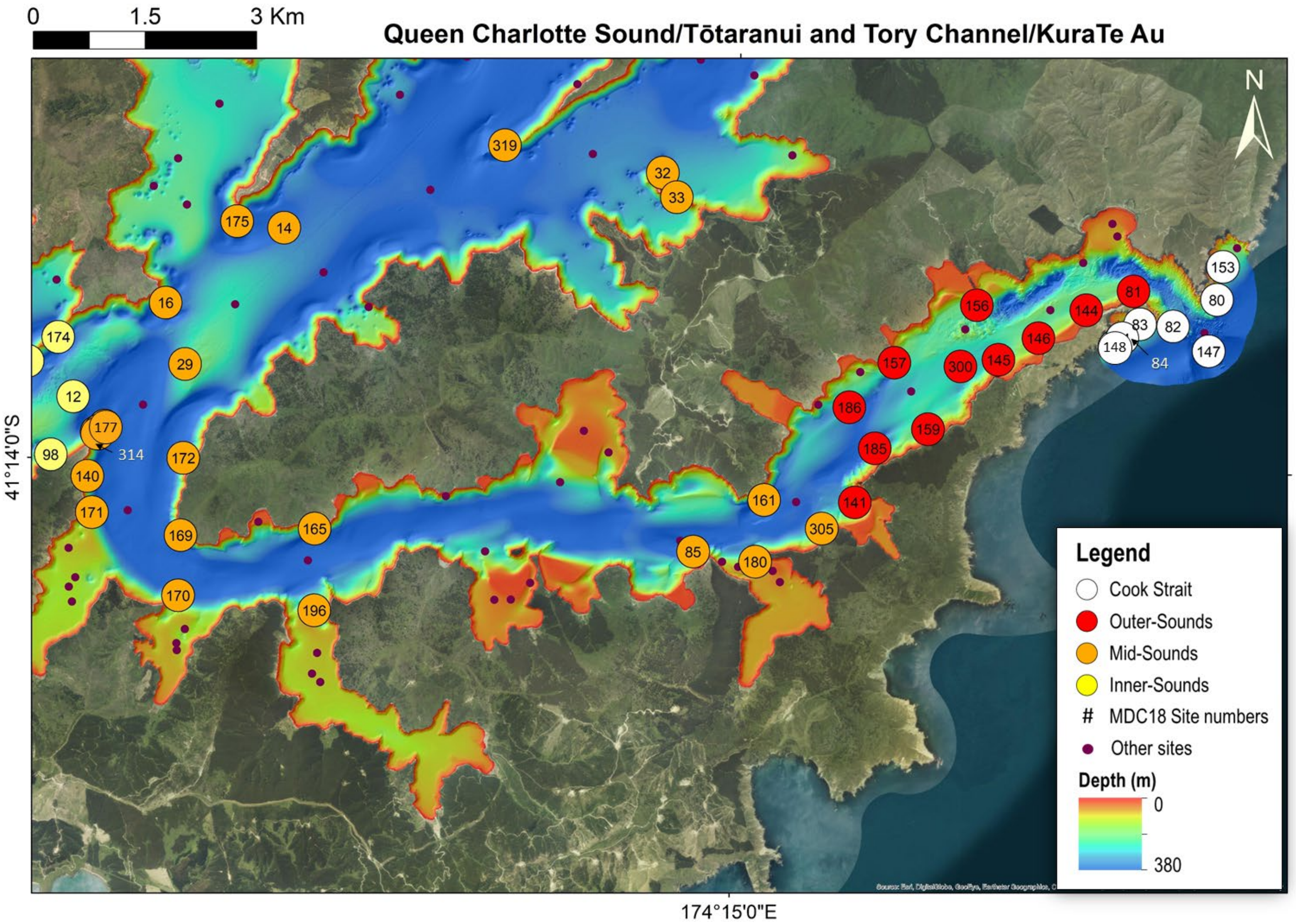
Appendix B Zoomed-in map of MDC18 site locations - Outer QCS and Cook Strait.



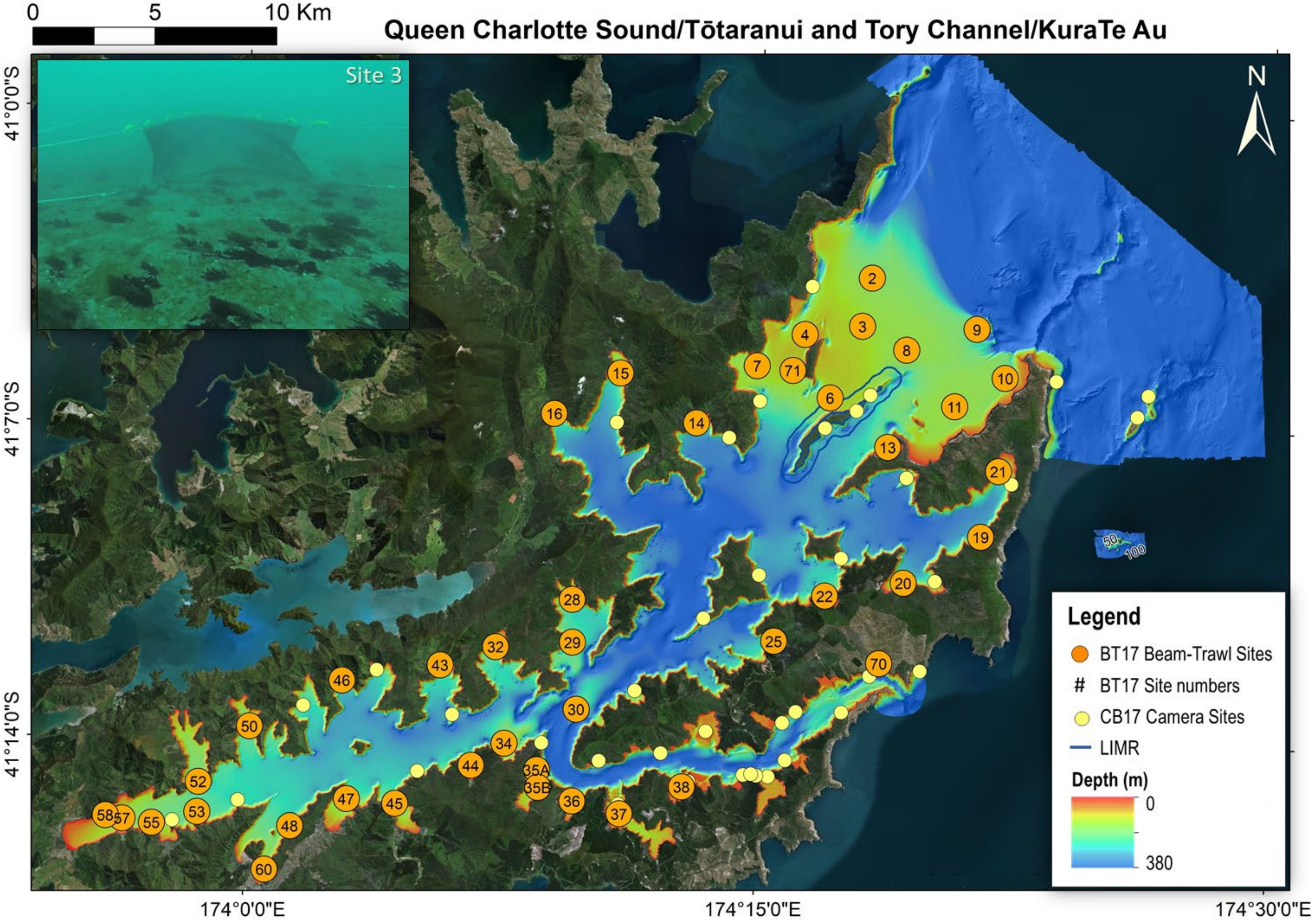
# Appendix C	Zoomed-in map of MDC18 site locations - Inner and mid QCS.



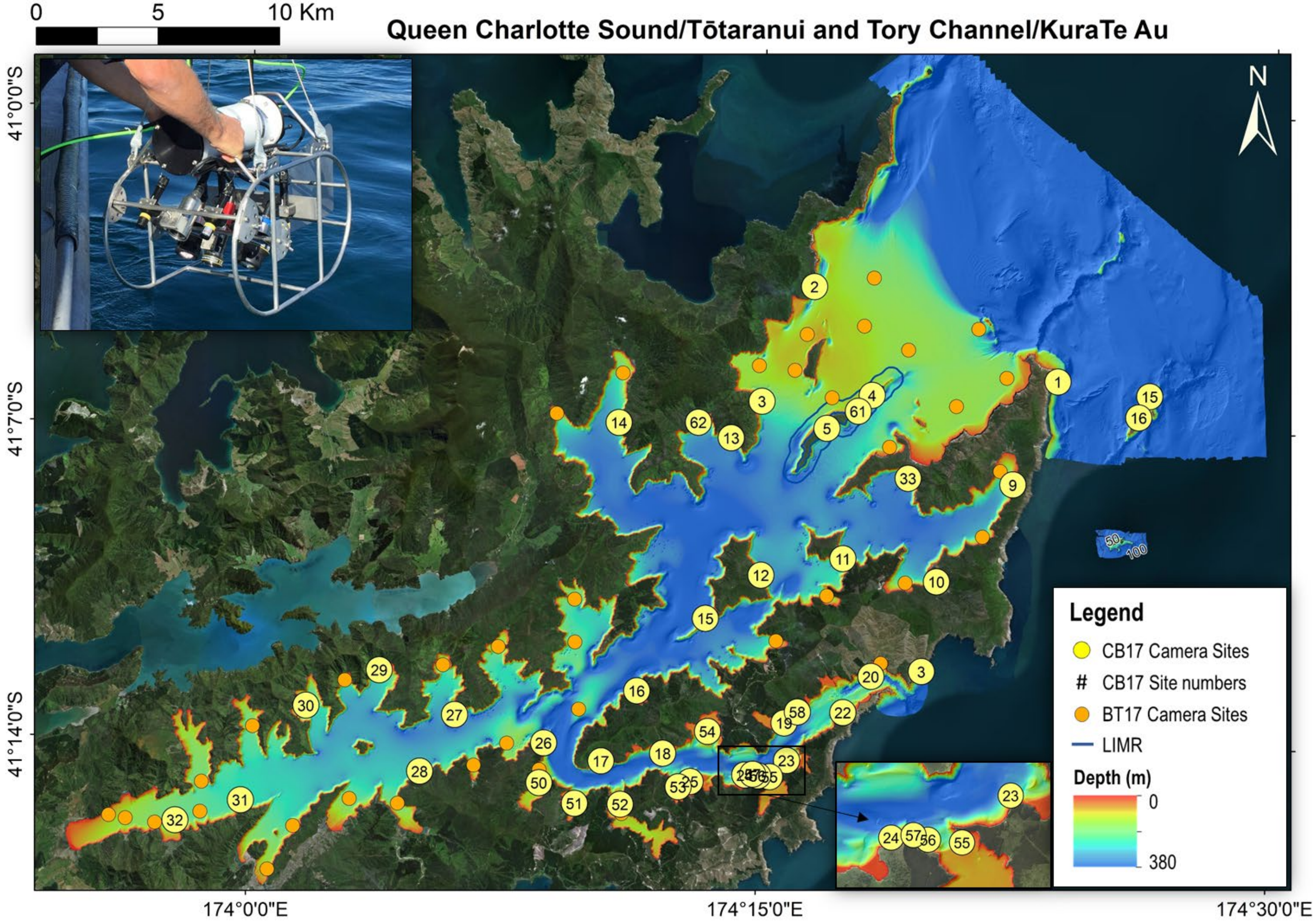
Appendix D Zoomed-in map of MDC18 site locations - TC.



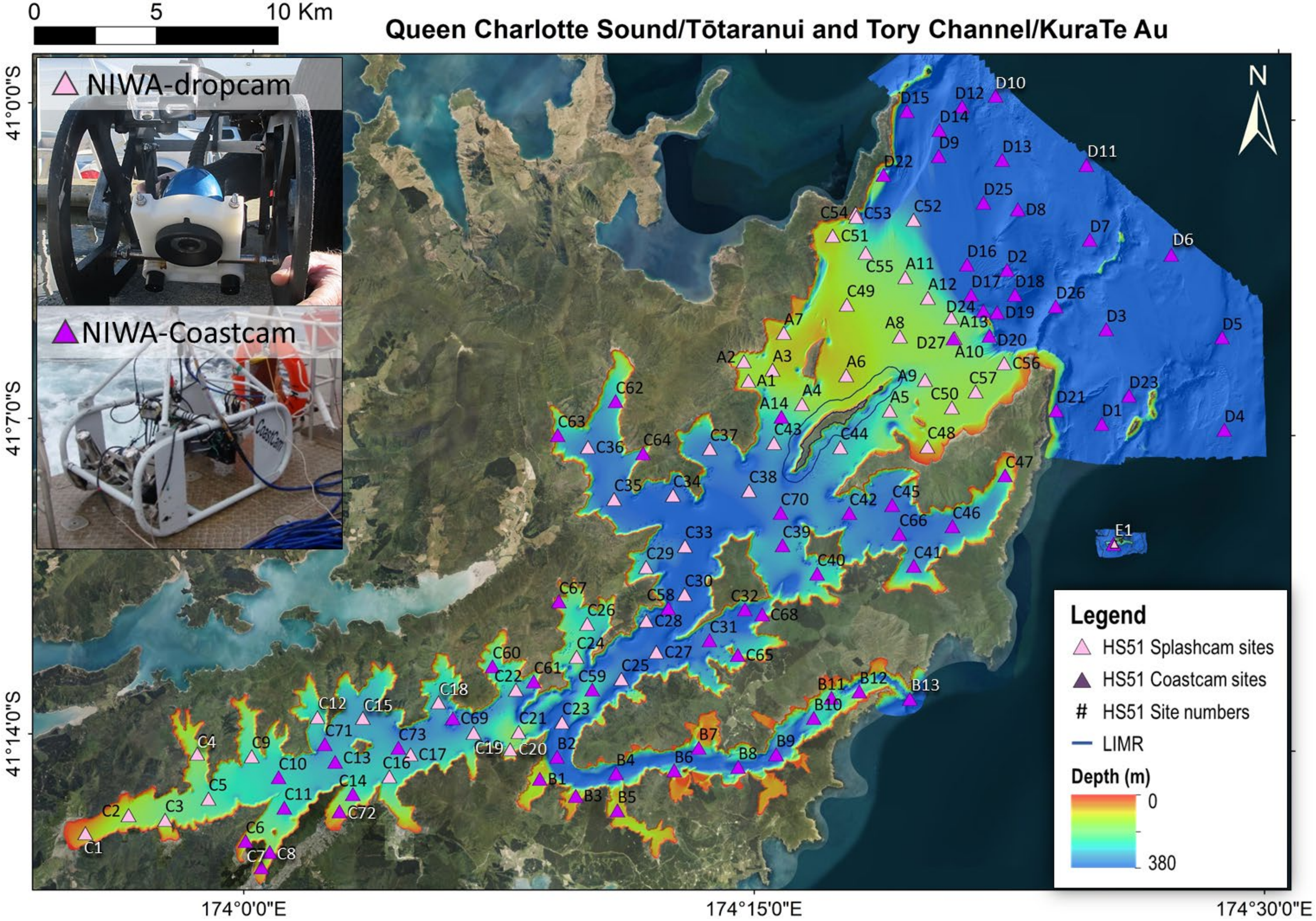
Appendix E Map of MBIE-BT17 Beam trawl (with GoPro-video) site locations.



Appendix F Map of MBIE-CB17 Tow-video (CBedcam) site locations.



Appendix G Map of HS51 Drop-camera site locations.



Appendix H Site locations and summary depths for the MDC18 video survey

Table H-1: Summary statistics for horse mussels (rank counts and depth ranges) for the MDC18 survey. QCS=Queen Charlotte Sounds; TC=Tory Channel; Occur (%) = Number of observation calls (% of all MDC18 data records) for stations where *Atrina* were present. Rank abundance for areas where *Atrina* were present are 1, 3, or 10 per data record (15 second window), where: 1 = 1–2, 3 = 3–5, and 10 = 5–15 individuals per data record. Geometric means [GM mean] are presented to give an appropriate estimated mean value from rank abundance counts; range is the minimum-maximum raw rank value at each site. n/a = no range could be provided as <3 records of *Atrina* at the site. Bold values depict sites with higher numbers of *Atrina* (GM mean >3), underlined values depict intermediate numbers (GM mean 2-3) with >3 *Atrina* occurrences.

survey	area	Site	Occur (%)	Rank abundance		Depth (m)	
				GM mean	Range	Mean (±SE)	Range (m)
MDC18	Inner QCS	Q04	3 (10%)	1.0	1-1	29.8 (0.9)	28.7-31.6
MDC18	Inner QCS	Q05	7 (39%)	1.4	1-3	23.6 (2.1)	16.0-29.4
MDC18	Inner QCS	Q07	3 (7%)	1.4	1-3	30.1 (1.1)	28.9-32.3
MDC18	**Inner QCS**	**Q08**	**12 (44%)**	**3.6**	**1-10**	**22.8 (1.9)**	**11.0-29.7**
MDC18	Inner QCS	Q09	1 (3%)	1.0	n/a	15.4	n/a
<u>MDC18</u>	<u>Inner QCS</u>	<u>Q10</u>	<u>11 (52%)</u>	<u>2.3</u>	<u>1-10</u>	<u>8.4 (0.3)</u>	<u>6.1-9.9</u>
<u>MDC18</u>	<u>Inner QCS</u>	<u>Q11</u>	<u>12 (34%)</u>	<u>2.6</u>	<u>1-10</u>	<u>14.3 (1.3)</u>	<u>9.1-19.9</u>
MDC18	Inner QCS	Q12	4 (15%)	1.3	1-3	39.0 (1.1)	36.7-41.6
MDC18	Inner QCS	Q89	4 (7%)	1.3	1-3	23.7 (3.9)	13.9-32.6
MDC18	Inner QCS	Q90	4 (9%)	1.0	1-1	28.1 (0.6)	26.9-29.2
<u>MDC18</u>	<u>Inner QCS</u>	<u>Q92</u>	<u>8 (19%)</u>	<u>2.3</u>	<u>1-10</u>	<u>17.1 (1.7)</u>	<u>12.8-26.5</u>
MDC18	Inner QCS	Q93	6 (22%)	1.0	1-1	16.6 (3.3)	8.1-27.9
MDC18	Inner QCS	Q94	7 (23%)	2.2	1-3	20.9 (2.0)	15.1-28.9
MDC18	**Inner QCS**	**Q95**	**4 (40%)**	**4.6**	**3-10**	**20.8 (0.6)**	**19.5-22.0**
MDC18	**Inner QCS**	**Q96**	**5 (19%)**	**4.0**	**1-10**	**13.5 (1.6)**	**9.4-18.5**
MDC18	Inner QCS	Q97	4 (10%)	1.7	1-3	33.7 (5.1)	21.1-43.2
MDC18	Inner QCS	Q98	3 (12%)	1.4	1-3	15.7 (2.4)	12.4-20.4
MDC18	Inner QCS	Q99	2 (9%)	1.7	1-3	13.0 (0.3)	12.7-13.2
MDC18	Inner QCS	Q100	2 (10%)	1.0	1-1	21.9 (1.1)	20.8-23.0
MDC18	Inner QCS	Q101	5 (16%)	1.0	1-1	23.9 (3.4)	16.6-32.5
MDC18	Inner QCS	Q102	2 (4%)	1.0	1-1	28.3 (5.4)	22.9-33.7
MDC18	Inner QCS	Q103	11 (29%)	1.1	1-2	18.5 (2.6)	8.9-29.1
MDC18	Inner QCS	Q104	2 (7%)	1.0	1-1	19.6 (10.1)	9.4-29.7
MDC18	Inner QCS	Q106	2 (6%)	1.0	1-1	28.6 (0.4)	28.2-29.0
MDC18	Inner QCS	Q107	6 (19%)	1.2	1-3	20.3 (2.3)	14.2-25.7
MDC18	Inner QCS	Q174	1 (4%)	3.0	n/a	21.4	n/a
MDC18	Inner QCS	Q178	3 (14%)	1.0	1-1	18.6 (2.9)	12.8-22.4
MDC18	Inner QCS	Q179	2 (9%)	1.0	1-1	29.2 (1.6)	27.7-30.8

survey	area	Site	Occur (%)	Rank abundance		Depth (m)	
				GM mean	Range	Mean (±SE)	Range (m)
MDC18	**Inner QCS**	**Q193**	**19 (63%)**	**7.3**	**1-10**	**19.7 (1.1)**	**11.6-25.2**
MDC18	Inner QCS	Q197	4 (14%)	2.7	2-3	8.5 (1.3)	4.7-10.9
MDC18	Inner QCS	Q313	1 (6%)	1.0	n/a	31.9	31.9-31.9
MDC18	Inner QCS	Q320	4 (11%)	1.0	1-1	15.5 (1.1)	12.2-17.0
MDC18	Inner QCS	Q321	10 (48%)	1.9	1-3	16.1 (1.0)	10.9-19.5
MDC18	**Inner QCS**	**Q322**	**4 (9%)**	**4.1**	**3-10**	**16.0 (1.4)**	**12.8-19.0**
MDC18	Mid QCS	Q16	1 (3%)	1.0	n/a	33	n/a
MDC18	Mid QCS	Q18	2 (8%)	1.0	1-1	45.8 (0.4)	45.4-46.3
MDC18	Mid QCS	Q29	6 (25%)	1.2	1-3	29.4 (1.6)	25.8-36.5
MDC18	Mid QCS	Q33	2 (3%)	1.0	1-1	25.8 (0.0)	25.8-25.8
MDC18	Mid QCS	Q36	2 (6%)	1.0	1-1	37.1 (1.4)	35.7-38.5
MDC18	Mid QCS	Q39	1 (5%)	1.0	n/a	35.8	n/a
MDC18	Mid QCS	Q40	3 (10%)	1.4	1-3	40.7 (0.4)	39.9-41.1
MDC18	Mid QCS	Q42	1 (2%)	3.0	n/a	33.7	n/a
MDC18	Mid QCS	Q44	1 (4%)	3.0	n/a	29.6	n/a
MDC18	Mid QCS	Q45	2 (9%)	1.0	1-1	45.9 (1.8)	44.1-47.7
MDC18	Mid QCS	Q73	4 (14%)	1.3	1-3	23.9 (4.4)	15.2-32.1
MDC18	Mid QCS	Q74	6 (21%)	1.0	1-1	21.3 (0.6)	18.4-22.6
MDC18	Mid QCS	Q175	1 (4%)	1.0	n/a	6	n/a
MDC18	Mid QCS	Q176	1 (4%)	1.0	n/a	30.1	n/a
MDC18	Mid QCS	Q317	2 (13%)	1.0	1-1	46.8 (0.2)	46.6-47.0
MDC18	Mid QCS	Q318	9 (26%)	1.9	1-3	30.8 (1.4)	24.5-37.8
MDC18	Mid QCS	Q319	1 (2%)	1.0	n/a	23.3	n/a
MDC18	Outer QCS	Q20	1 (4%)	1.0	n/a	25	n/a
MDC18	Outer QCS	Q21	2 (10%)	1.0	1-1	27.7 (0.2)	27.4-27.9
MDC18	Outer QCS	Q22	3 (8%)	3.0	3-3	38.5 (0.0)	38.4-38.5
MDC18	Outer QCS	Q24	1 (2%)	1.0	n/a	24.2	n/a
MDC18	**Outer QCS**	**Q27**	**21 (100%)**	**3.0**	**1-10**	**17.0 (0.7)**	**11.0-20.6**
MDC18	**Outer QCS**	**Q28**	**22 (61%)**	**3.6**	**1-10**	**22.8 (0.3)**	**20.6-24.2**
MDC18	Outer QCS	Q47	4 (15%)	1.2	1-2	44.0 (4.5)	32.4-52.1
MDC18	**Outer QCS**	**Q51**	**7 (11%)**	**3.1**	**1-10**	**33.6 (1.6)**	**26.6-38.0**
MDC18	Outer QCS	Q56	3 (6%)	1.0	1-1	21.3 (0.0)	21.3-21.3
MDC18	Outer QCS	Q57	1 (2%)	1.0	n/a	24.5	n/a
MDC18	Outer QCS	Q58	1 (3%)	1.0	n/a	16.5	n/a
MDC18	Outer QCS	Q59	4 (8%)	1.0	1-1	17.6 (2.7)	9.9-22.1
MDC18	Outer QCS	Q67	4 (5%)	1.0	1-1	36.2 (8.4)	12.2-51.4
MDC18	Outer QCS	Q68	3 (5%)	1.0	1-1	33.3 (3.0)	27.6-37.7
MDC18	Outer QCS	Q72	2 (7%)	1.0	1-1	32.4 (0.1)	32.4-32.5

survey	area	Site	Occur (%)	Rank abundance		Depth (m)	
				GM mean	Range	Mean (±SE)	Range (m)
MDC18	Outer QCS	Q118	2 (5%)	1.4	1-2	22.3 (0.1)	22.2-22.4
MDC18	Outer QCS	Q119	2 (6%)	1.0	1-1	25.8 (0.2)	25.6-25.9
MDC18	Outer QCS	Q127	1 (4%)	1.0	n/a	29.5	n/a
MDC18	Outer QCS	Q190	6 (18%)	1.0	1-1	23.4 (0.0)	23.3-23.5
MDC18	Outer QCS	Q316	2 (7%)	1.4	1-2	30.5 (1.0)	29.6-31.5
MDC18	Outer QCS	Q22b	3 (15%)	1.0	1-1	36.1 (0.4)	35.4-36.8
MDC18	Inner TC	Q177	2 (9%)	1.0	1-1	27.0 (3.3)	23.7-30.2
MDC18	Inner TC	Q177	2 (5%)	1.0	1-1	27.0 (3.3)	23.7-30.2
MDC18	Inner TC	Q314	3 (11%)	1.0	1-1	30.8 (1.2)	28.3-32.1
MDC18	Mid TC	Q180	5 (2%)	1.0	1-1	30.9 (0.1)	30.6-31.3
MDC18	Outer TC	Q186	13 (24%)	2.5	1-3	38.4 (0.1)	38.0-38.8

Appendix I Comparative example of a moderate to dense horse mussel bed, recorded outside the study area.

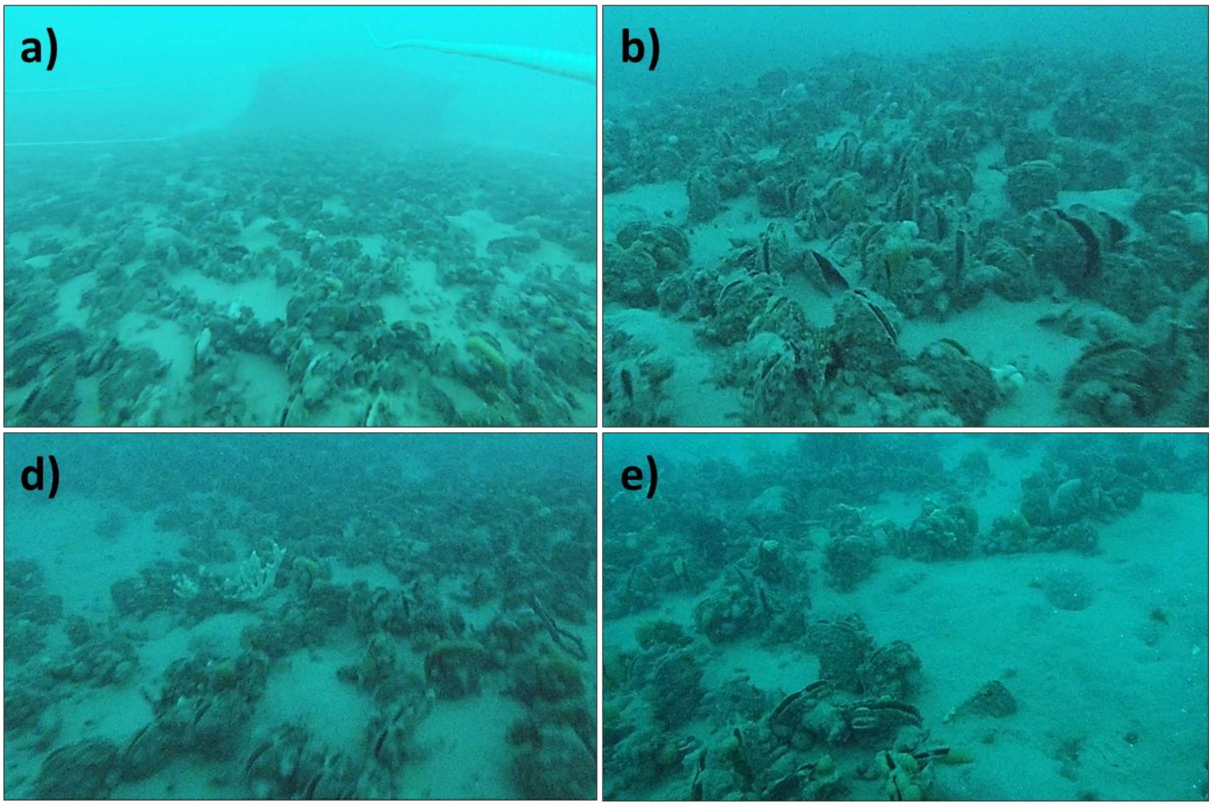


Figure B-1: Comparative example of a moderate to dense horse mussel bed (*Atrina zelandica*) from Chetwode Islands, outer Marlborough Sounds (a site beyond the HS51 survey area). Images show a moderately high density *Atrina* bed (est. 17–34 horse mussels per m^2) located on the Outer Sounds banks east of the Chetwode Islands (latitude -40.9143, longitude 174.1258), where 37 horse mussels were also collected during the BT17 survey with mean shell length of 234.8 mm ± 40.7 SD (Shell length range 155–290 mm). Photos: Tara Anderson, MBIE Bottlenecks programme (CO1X1618).