Marine Bioservices

Review of Pelorus Sounds multibeam seafloor mapping (HS66): The next steps to identify and map important sites of marine biodiversity.

Prepared for Marlborough District Council

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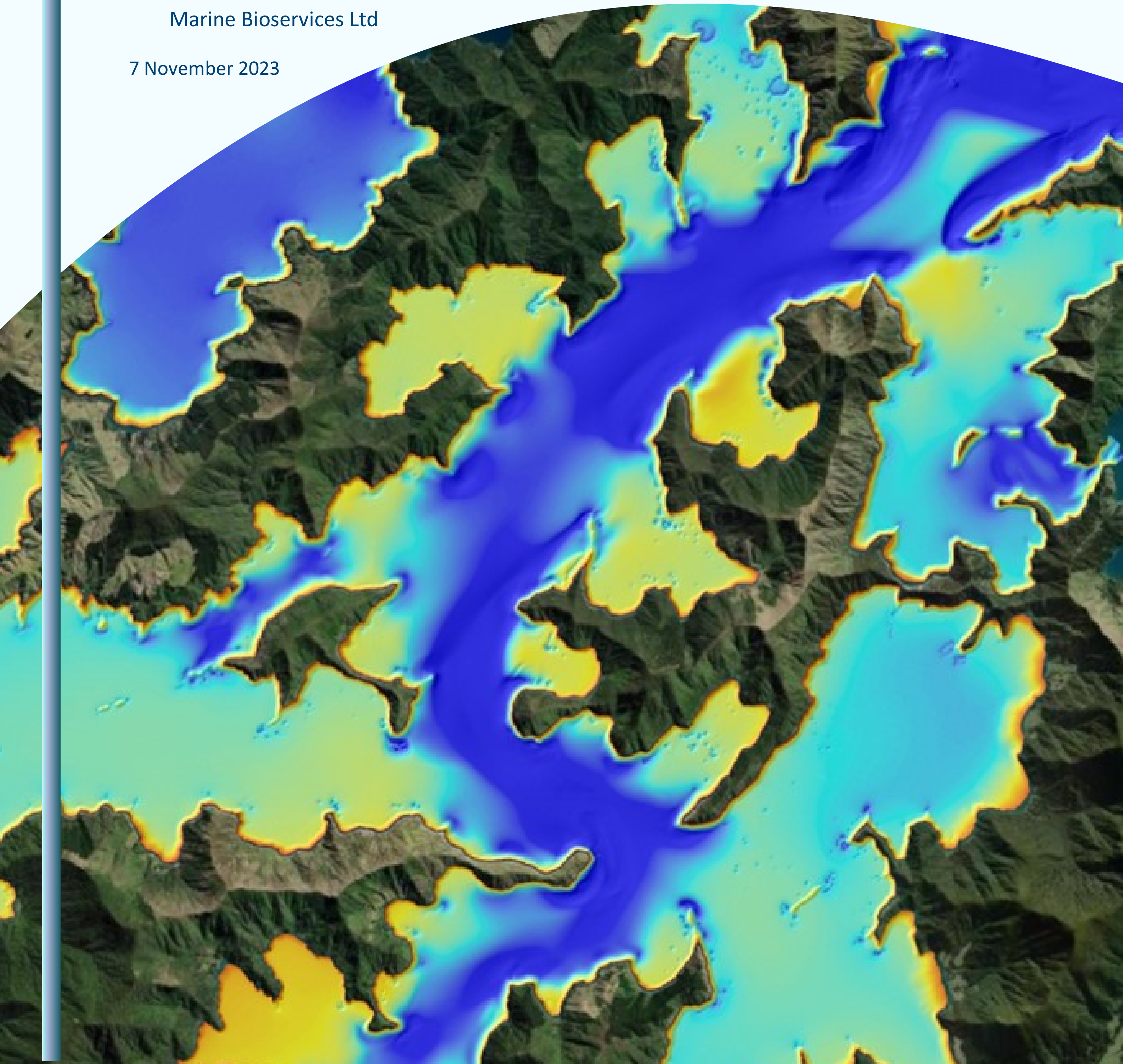
7 November 2023



Review of Pelorus Sounds multibeam seafloor mapping (HS66): The next steps to identify and map important sites of marine biodiversity

Dr Tara J. Anderson

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1 Executive Summary

In 2019, Marlborough District Council (MDC) and Land Information New Zealand (LINZ) contracted iXBlue (now called Ocean Infinity) and Discovery Marine Ltd. (DML) to collect Multibeam Echo Sounding (MBES) across five main subregions of the western Marlborough Sounds (French Pass and Admiralty Bay / Te Aumiti and Pelorus Sounds / Te Hoiere under the LINZ Project HYD-2018/19-01 (HS66)). Four subregions (French Pass, Admiralty Bay, North Pelorus and Popoure Reach) were surveyed by iXblue using a Kongsberg 2040 Mk II multibeam echosounder (MBES) system; with the fifth subregion (Pelorus South) surveyed by DML using a Teledyne RESON SeaBat T50-R MBES. Together these hydrographic surveys (HS66) acquired seafloor bathymetry, backscatter and water column data across 324.59 km^2 of seafloor in Western Marlborough Sounds (HS66 survey area).

This report provides a review of what physical and biological data are available; how these data and imagery can be used; and, what additional data is required to help identify and map important sites of marine biodiversity.

Ground truthing data: A total of 331 existing ground truthing sites, which already have habitat and associated biological descriptions, were evaluated as part of this review. Metadata for an additional ≥1163 sites, was also identified. The latter includes a potentially rich source of ground truthing information, that would be valuable to access, collate and evaluate against the MBES layers.

Of the available 331 sites, 273 sites represented recent ground truthing surveys (Orpin et al. 2020; Davidson et al. 2022) while 58 represented historic sites (Estcourt, 1967; McKnight and Grange, 1991). Grain size composition (%mud, sand and gravel) was also available for an additional 203 sites (MDC SmartMap website).

New CBed substratum classifications, identical to those used in the HS51 region (Anderson et al. 2020) were created for all published descriptions of sites surveyed within the HS66 survey area. These were plotted over the MBES layers to preliminary examine how accurately they described these seafloor habitats and communities. A new ‘shell-debris rank-%cover’ variable was created, that ranked the amount of shell recorded at a site from 0 denoting no shell, up to 5 denoting large amounts of shell. If key taxa were described, these were converted to ‘presence’ records.

The new CBed classification layers were then plotted over the various MBES-HS66 layers to examine how well they visually aligned with these layers and, then how well each physical layer could be used to predict significant habitats and communities. For example, observations of mud, shell-debris, and rugose rock habitats aligned extremely well with NIWA’s ‘Preliminary Seafloor Classification’ (SRC) layer, validating this layer as useful for depicting differences in seafloor composition. Differences in the amount of shell debris on the seafloor was also visually aligned with changes in near-bottom current strength.

Existing habitat maps created by Cawthron for three localised sites, also aligned well when plotted over NIWA’s SRC layer. This ability to zoom out from localised sites to gain a larger spatial assessment of habitat availability (and hence relative impact scales) will be a valuable tool for MDC. Here, shell-debris zones mapped around all three sites (i.e., Richmond and Waitata farms, and Kaitira), extended well beyond all three sites, with delineated boundaries visible in the SRC layer. The locations of these shell-debris boundaries also spatially-aligned (nearly a 1:1 match) near-bed current speeds, indicating useful predictive relationship between these layers. These are just a few examples of the types of seafloor habitat/biological predictions that can be made by visually examining these various layers together.

Bathymetry and derived terrain attributes: The current bathymetric and derived-attribute maps have been processed at 2 m and 1 m grid resolutions and are now available to MDC both as visual maps and as quantitative rasters.

These layers can already be used to visually (qualitatively) detect significant habitats and their communities within the HS66 survey area. Comparisons between the HS51 and HS66 survey areas, also means that qualitative and quantitative predictions made for the HS51 region, should provide fruitful for the HS66 region, too. For example, 1) 'bryozoan patch-reefs' at the entrance to Pelorus Sounds / Te Hoiere have been predicted and delineated based on high seafloor roughness, slightly raised bathymetry, and low associated rugosity, and known relationships from the HS51 survey, but need to be validated. 2) two spatially separated biodiverse biogenic habitat zones in the southern passage of French Pass have now been verified and delineated (based on rugosity, backscatter, roughness, & recent and historic ground truthing).

Benthic terrain classifications (BTC): NIWA generated **14 benthic terrain classifications** (BTC) (Maier et al. 2021), using the same 14 geomorphic classifications used by Neil et al. (2018) for the Eastern Sounds (HS51 survey).While these 14 categories may be perfectly valid geomorphically, these zones provided little predictive insight to where significant habitats and biodiverse communities occur in either the HS51 survey (T. J. Anderson, Stewart, et al. 2020) or, based on this preliminary review, this recent HS66 survey. However, while this layer may not provide much biological-insight on its own, it may provide some insight in some localised situations.

Rock outcrops layer: The BTC class=10 classified areas of '*Rock Outcrop Highs, Beach Platform, Narrow Ridges*' with a calculated area of 10.11 km^2 (3.11%) within the HS66 survey area. Visual evaluation at large to medium spatial scales identified that most rock features were included in class-10, however, some non-reef habitats (e.g., raised mud banks) were also incorrectly included. At finer-scales individual rock features often did not match the shape or boundaries of this class, with some rock features mismatches by up to c. ≤40%.

This identifies that this class should not be used to represent true rock outcrop area; and that a more representative fine-tuned classification of rock outcrops is still required. The creation of an accurate rock out crop layer is important for both qualitative (visual) and quantitative predictions, and as such the creation of this layer should be prioritised. In the HS51 survey, a more refined rock outcrops layer was produced, and was very good at aligning with most rock outcrop features, but also failed to identify or delineate small deeper rock features – including some significant biological sites. Therefore, the method used to delineate Rock Outcrops in both regions could be improved based on a single revised approach.

Backscatter imagery and data are extremely useful for predicting (inferring) seafloor composition (hard to soft). Both the coarse field-mosaiced backscatter imagery (created by iXblue from unprocessed raw data for ground truthing) and the geo-rectified image of NIWA's preliminary SRC layer have already helped to predict and discriminate several significant habitat and community types (e.g., bryozoan patch reefs, several mixed-biogenic debris-fields) within the HS66 region. In addition, predictions from the HS51 survey (e.g., *Amphiura*-dominated sediment plain boundaries) are also likely to prove useful in the HS66 area. Evaluation of the NIWA's preliminary SRC layer using the new CBed-classifications found that the seafloor observations aligned well with NIWA's four reflectivity classes, and although further evaluation is required, based on this review it is already fit for MDC's purposes with no additional processing required.

With the eastern Sounds (HS51 survey area), NIWA's HS51-SRC raster layer was used in habitat suitability models, where it was an important quantitative predictor of: the distribution and abundance of several significant biogenic habitat formers, incl: *Galeolaria hystrix* mounds, bryozoan patch-reef zones, horse mussel beds (*Atrina zelandica*); as well as the distribution and presence of other bivalve species (Ribó et al. 2021). In this review, a comparison of the eastern (HS51) and western

(HS66) regions found strong similarities between near-bottom current strength and seafloor reflectivity in both regions - indicating that predictions from one region (i.e., HS51) should prove fruitful in the other (i.e., HS66), or vice versa. If quantitative predictions are to be used this would necessitate the use of a seafloor reflectivity raster layer.

Fully-processed and calibrated backscatter imagery and an equivalent-classed seafloor reflectivity layer are time consuming projects. However, in the interim, there is plenty of valuable information in the existing available data layers (i.e., MBES, near-bottom current speeds, and existing ground truthing data) to begin visually (qualitatively) interrogating these various layers to predict areas of likely biological significance.

Not processing the backscatter data would mean that the full processed seafloor backscatter mosaic (image and raster/data) would not be available to help inform either the visual (qualitative) or the analytical (quantitative) approaches (e.g., habitat suitability modelling). This would be a great loss of information that may hinder the ability to detect, and therefore protect, significant habitats and diverse biological communities.

Water column data: Using backscatter signals from the water column to detect biological structure growing above the seafloor, is still a relatively new area of research that shows excellent promise for surface-growing species (e.g., *Macrocystis*), while species growing closer to the seafloor (e.g., *Ecklonia*) are still difficult to accurately discern (Schimel et al. 2020). In the HS51 survey area water column backscatter was able to discern a lost cray line out in Cook Strait. However, its overall value to predict macroalgae was poor, due to high numbers of erroneous records of kelp where no kelp was present, including predictions of kelp beds out over expansive mud embayment's where no reef exists (T. J. Anderson, Stewart, et al. 2020). Consequently, commercial avenues for processing these data are not recommended, however this would make an excellent graduate-Thesis project. Kelp forests and *Caulerpa* beds growing in extremely exposed hard to survey sites, would make a great targeted assessment of the value of this method. This would help determine where likely above-reef macroalgae might exists, so that these exposed areas could be more accurately targeted and mapped.

What new ground truthing data is required? The available suite of predictive environmental layers (MBES, currents, spatial derivatives) and data (ground truthing imagery and classifications) can already be used to predict likely sites supporting significant habitats and marine biodiversity. While some of these sites may already align with existing ground-truthing data, others, like the bryozoan patch-reefs have no information to validate this prediction or characterise their biodiversity. Targeted tow-video transects in these newly predicted significant habitats are recommended. This would: i) validate these newly predicted sites; ii) characterise the biodiversity and within-habitat variability at these sites; and, iii) adequately ground truth the position of boundaries relative to visual boundaries in the MBES-maps, so that the boundaries of these sites can be mapped, and their significance assessed.

2 Introduction

2.1 Background

In 2019, Marlborough District Council (MDC), in collaboration with LINZ, contracted iXBlue and DML to collect Multibeam Echo Sounding (MBES) data across 325 km^2 of seafloor within the Western Marlborough Sounds (identified as survey HS66) that included Pelorus Sounds/ Te Hoiere (blocks: north and south Pelorus and Popoure Reach), Te Aumiti/French Pass and Admiralty Bay. The HS66 survey used two MBES systems, following the methods used in the HS51 survey of Queen Charlotte Sound/ Totaranui, to provide consistency between survey areas. The iXblue survey used a Kongsberg 2040, while the DML survey used a Reson SeaBat T50 multibeam echo sounder system to map their respective areas of the western Marlborough Sounds (HS66 survey area). To minimise changes of acoustic energy transmitted, both surveys used the same “controlled frequency (300 kHz) and pulse length”, enabling “consistent backscatter response to the seafloor and water column across all depths” (Mackay et al. 2020). During the HS66 surveys a series of sediment grabs were collected across the survey area (31 by iXblue and 16 by DML) to provided ground truthing information. A section of seafloor in Waitata Bay (termed ‘Waitata Bay reference surface’ in Mackay et al. 2020) was resurveyed at multiple times over the duration of the survey to enable calibration of the MBES survey data (iXblue and DBL reports, 2020).

Following the iXBlue and DML MBES surveys, NIWA was contracted to i) undertake quality assurance checks of all backscattered data for the western Marlborough Sounds survey (HS66) (described in Mackay et al. 2020); and ii) undertake a ground-truthing survey that collected sediment samples (135 grabs) and benthic community observations (165 drop-video sites) across the HS66 survey area (referred to as the ‘western Marlborough Sounds’). In the ground truthing survey, NIWA allocated sediment-grab and towed-video sites to a provisional ‘Seafloor Reflectivity Classification’ (SFR) layer created from a training set of four backscatter classes following the methods used in the HS51 survey (as described in Orpin et al. 2020).

MDC, through the costly process of contracting the HS66 survey, made the conscious decision to maximise the extent of the MBES survey area (collect multibeam data over more of Pelorus Sounds), rather than focus on processing the HS66 MBES data to the same extent as the HS51 survey (at that time). This meant that for the HS66 survey, the priority was to process all of the multibeam bathymetry, and key derived bathymetric layers (e.g., seafloor slope rugosity, aspect and curvature). Benthic Terrain Models (derived from the MBES HS66 data), were later process and provided by the Ministry of Primary Industry (MPI) under subsequent funding. However, it was evident that MDC was unable to fund the full processing costs of these layers, as well as those of the water column or seafloor backscatter layers through previous avenues (consistent with the HS51 survey). Therefore, whilst the raw water column and seafloor backscatter data is available and has been quality assured and checked (Mackay et al. 2020), water column and seafloor backscatter data were not able to be processed, at that time. Consequently, MDC to date does not have processed water column or seafloor backscatter layers.

MDC has since been allocated additional funding to best utilise the HS66 data over the next 5 years. MDC are now considering how the existing HS66 data can be used, what the consequences of not having the backscatter are, and if required, if and how a collaborative research model may work best, in this situation. MDC now need expert advice on how they should proceed, to determine how the HS66 Multibeam Echo Sounding (MBES) data can best be used, (and potentially processed) for the purpose of identifying important sites of marine biodiversity in the most effective and cost-efficient way.

2.2 Scope of project

In the eastern Marlborough Sounds (HS51 survey area), MBES data has proven itself invaluable as a foundation from which to identify areas of important biodiversity. The bathymetry along with several other derived-data layers (e.g., slope and rugosity) not only provides critical information for navigational safety, but also provides invaluable information on the shape, slope and complexity of the seafloor. For the HS66 survey, these data layers have already been processed and are available currently. However, unlike the HS51 survey, MDC, have not yet had the HS66 seafloor backscatter or water column data processed, although the HS66 backscatter has been quality checked and cleaned by NIWA (Mackay et al. 2020), and provisional training backscatter data has been post-processed by NIWA for the purposes of allocating ground truthing sample sites to four preliminary seafloor classification levels following the methods used in the HS51 survey (as described in Orpin et al. 2020). However, this processed backscatter has not been provided to MDC. MDC now requires critical advice on the different ways the HS66 data could be utilised for a similar aim to outputs from the HS51 data. To do this, some key questions to consider and address here are:

- Is it essential to process the backscatter data?
- What are the benefits of having the backscatter data processed?
- What are the benefits/ pitfalls of not processing the data?
- What are the best methods/options that could be used for the existing HS66 data to identify marine biodiversity?
- What geological surficial samples (i.e., surface sediment samples) and benthic biological sampling/survey (i.e., video observations and epibenthic samples) already exist within the HS66 survey area that could be used to identify significant biological areas?
- Can the existing HS66 datasets be used to predict significant habitats and species (i.e., using predictive habitat suitability modelling) as previously completed for the HS51 data, if not what other data (or data processing) is required?

As MDC's focus is primarily on identifying important sites of marine biodiversity, it is important to determine what the best methods for doing this, are.

Further to all this, in terms of identifying important sites of marine biodiversity,
is:

- What other information can be gleaned from the MBES data?
- What other ways could this information and data be used?
- What benthic biological data already exists within the HS66 area that might assist in these endeavours: particularly to ground-truth the MBES-HS66 maps, and to aid in the identification of important sites of marine biodiversity.
- What additional benthic biological data (i.e., new sampling sites) is required to identify and map benthic marine biodiversity across the western Marlborough Sounds; and predict important sites of marine biodiversity.
- Can the combination of MBES and benthic biological data from the combined HS51 and HS66 data be used in some way to help determine large-scale ecological change within the Sounds?

2.3 Approach

To address these aims, all of the available HS66 MBES data layers for the western Marlborough Sounds (HS66 survey area) was examined, relative to other available data layers. The location of digitally-available/known geological (sediment sampling) and benthic biological (video and/or biologically collected) sampling sites and associated information was overlayed in ArcGIS map format.

This combination of MBES and ground truthing data was assessed relative to the questions listed above, and the options available that include research collaborative and multi-disciplinary approaches are examined. HS66 MBES layers along with available ground-truthing data were examined relative to their use in characterising benthic biological diversity and predicting significant habitat and biodiversity following approaches used in the Eastern Marlborough Sounds (e.g., HS51 survey area: Anderson et al. 2020a; 2020b). Existing data and predictive modelling of key biogenic habitats has already been undertaken for the eastern Marlborough Sounds, and therefore can provide considerable predictive information that might be applicable to the Western Marlborough Sounds. Although this review does not go into modelling approaches per se, a review of how the HS51 data collected in the Eastern Sounds could be used to predict (and/or help predict) similar habitat, species and biodiversity in the Western Marlborough Sounds, was completed.

3 Existing data and knowledge

3.1 Physical data layers (what's been done)

Five main sub-regions were mapped in 2019 as part of the Western Marlborough Sounds HS66 multibeam mapping survey (HYD-2018/19-01, HS66; see boundaries in Figure 1), co-funded by Land Information New Zealand (LINZ) and the Marlborough District Council (MDC). IXblue surveyed four of the five sub-regions (i.e., Te Aumiti / French Pass and Admiralty Bay, Te Hoiere / North Pelorus and Popoure Reach; Figure 1), using a Kongsberg 2040 Mk II multibeam echosounder (MBES) system. DML surveyed the fifth sub-region (i.e., Te Hoiere / Pelorus South: purple boundary - Figure 1), using a Teledyne RESON SeaBat T50-R MBES (Maier et al. 2021). To ensure high quality data and seafloor mosaiced maps, both surveys used the same controlled frequency (300 kHz) and pulse length, and were calibrated by resurveying the same flat site within the Western Sounds HS66 survey area (i.e., Waitata Reference/calibration site, Pelorus South). In addition, to ensure that MBES-HS66 maps and data for the Western Sounds were also comparable to those from the Eastern Sounds MBES-HS51, the MBES-HS51 calibration site (i.e., "Waikawa Bay', Picton, Queen Charlotte Sounds) was also resurveyed (Mackay et al. 2020). These five sub-regions acquired seafloor bathymetry, backscatter and water column data from 324.59 km2 in Western Marlborough Sounds (i.e., HS66 survey area) (Mackay et al. 2020; Maier et al. 2021).

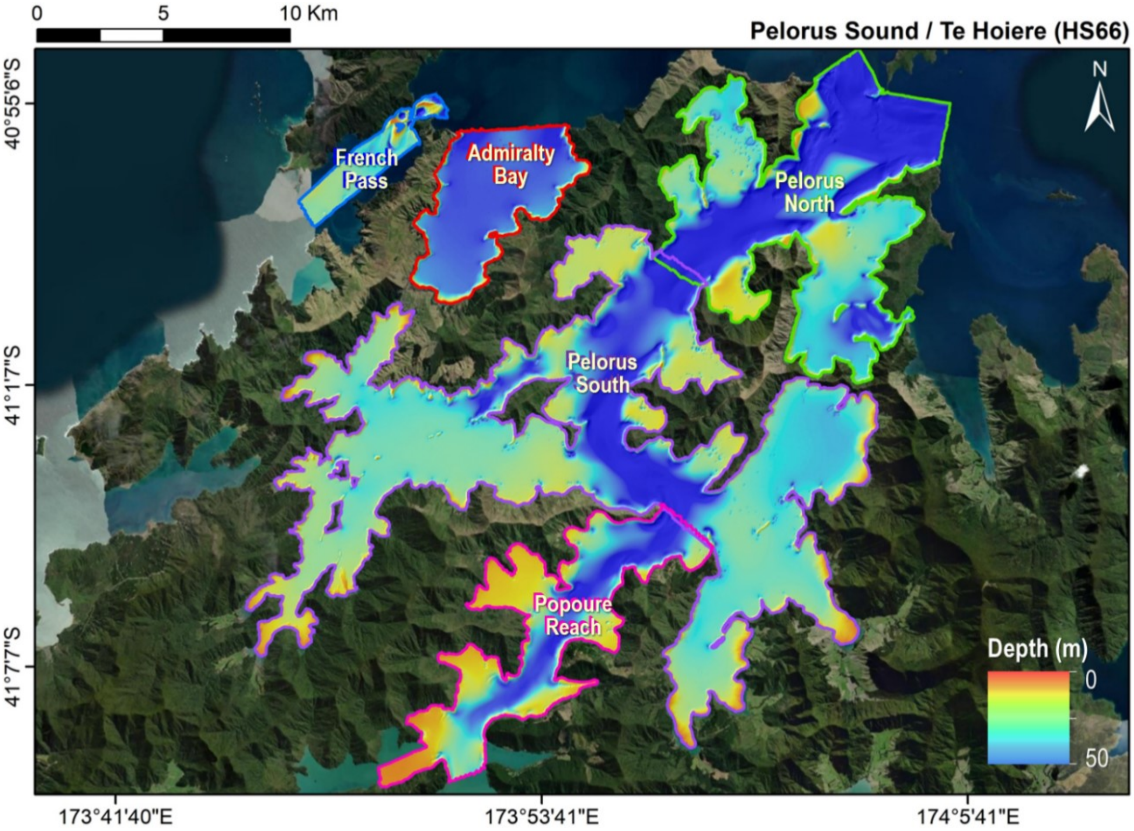

Figure 1. Multibeam echosounder (MBES) survey sub-regions (Area blocks), overlaid on the combined HS66 bathymetry layer. Pelorus South (purple boundary) was surveyed by DML, while all the other sub-regions seen here were surveyed by iXblue (*now owned by Ocean infinity*). Depths greater than 50 m are shaded blue to enhance more subtle nearshore depth changes.

3.1.1 Bathymetry

Following the completion of the HS66 surveys, MDC and LINZ funded the processing of all the HS66 bathymetry data for all five subregions, but not the backscatter data. Seafloor bathymetry, which provided the shape and depth of the seafloor across the HS66 survey area, was gridded at a resolution of both 1 m and 2 m (horizontal resolution) using Caris software. Finer-resolution grids also created for each subregion: Bathymetry was gridded at 1 m for French Pass/Te Aumiti; and 0.5 m for the other five subregions (M. Jacobson, MDC, *pers. comm.*). A 1 m and 2 m resolution gridded 'hillshade relief' layers were also generated with 3 times vertical exaggeration, with sun-illumination from the northwest 315° and altitude of 45^{+}, to provide improved depth visualisation (Maier et al. 2021; M. Jacobson, MDC, *pers. comm.*). In this review, the 1 m bathymetry is presented in a red-to-blue colour-swath scale, where depths are constrained to 0-50 m (i.e., depths > 50 m are all shaded/constrained to being dark blue) (Figure 1; Figure 2a). This was done here both to enhance more subtle depth changes in shallow waters within the Marlborough Sounds, and to be colour-consistent with the bathymetry layers published in the Port Folio maps for both the previous Eastern Marlborough Sounds (*HS51 survey in:* Neil et al. 2018) and for the current Western Marlborough Sounds (*HS66 survey in*: Maier et al. 2021) map products.

3.1.1.1 Benthic Terrain Model (BTM) classifications

Additional funding through Fisheries New Zealand (FNZ) in 2020, enable FNZ to commission NIWA to analyse the MBES HS66 data using ArcGIS Benthic Terrain Modelling toolbox (BTM: Wright et al. 2012) to create Benthic Terrain Classifications (Maier et al. 2021). Processed bathymetry data were imported into ArcGIS for spatial analysis and map compilation. Both the HS51 and HS66 multibeam bathymetry was analysed using ESRI's ArcGIS Benthic Terrain Modeller (BTM) to: 1) Generate a series of benthic terrain attributes from the bathymetric data (*i.e., depth; depth range; standard deviation of depth; slope; standard deviation of slope; aspect; curvature and rugosity*), and then 2) Use these datasets to generate a set of user-defined Benthic Terrain Classifications.

BTM is a standalone programme that is compatible with ArcGIS, that converts bathymetry into user-defined classifications, using a range of pre-written spatial analysis algorithms. The benthic terrain model overlays a bathymetric position grid (BPI) (see illustrative example in Figure 3a) and uses a neighbourhood analysis function to create benthic terrain classes based on similarities/differences between values in these different sized grids (Wright et al. 2005; Wright et al. 2012). Using the BTM toolbox, Maier et al. (2021) produced eight terrain attributes from the new HS66 bathymetry (*i.e., depth; depth range; standard deviation of depth; slope; standard deviation of slope; aspect; curvature and rugosity*).

The spatially gridded data, using calculations of the benthic positioning index (BPI) from depth, slope, rugosity and other geomorphic measures of seafloor shape were then analysed using a user-defined 'geomorphic' seafloor classification scheme. Here, the BTM examines standard deviation breaks in these various layers to help detect natural boundaries between seafloor features. This approach generated 14 benthic terrain (BT) classifications (Figure 2f; *see* Maier et al. 2021 *for more detailed portfolio maps*). These 14 BTM classification are also the same used for the HS51 survey area (Neil et al. 2018), consisting of flat plains; broad slopes; steep slopes; broad platforms or depressions; lateral mid-slope platforms or depressions; scarps (or cliffs); depressions; crevices or narrow gullies over elevated terrain; narrow slopes; rock outcrop highs, beach platforms or narrow ridges; and local depressions. The ArcGIS project and associated raster layers for the BTM classification (raster) layer and the benthic terrain attribute layers created to use in this model (e.g., slope, rugosity, aspect, curvature, etc.) were all supplied as part of the contract outputs Maier et al. 2021).

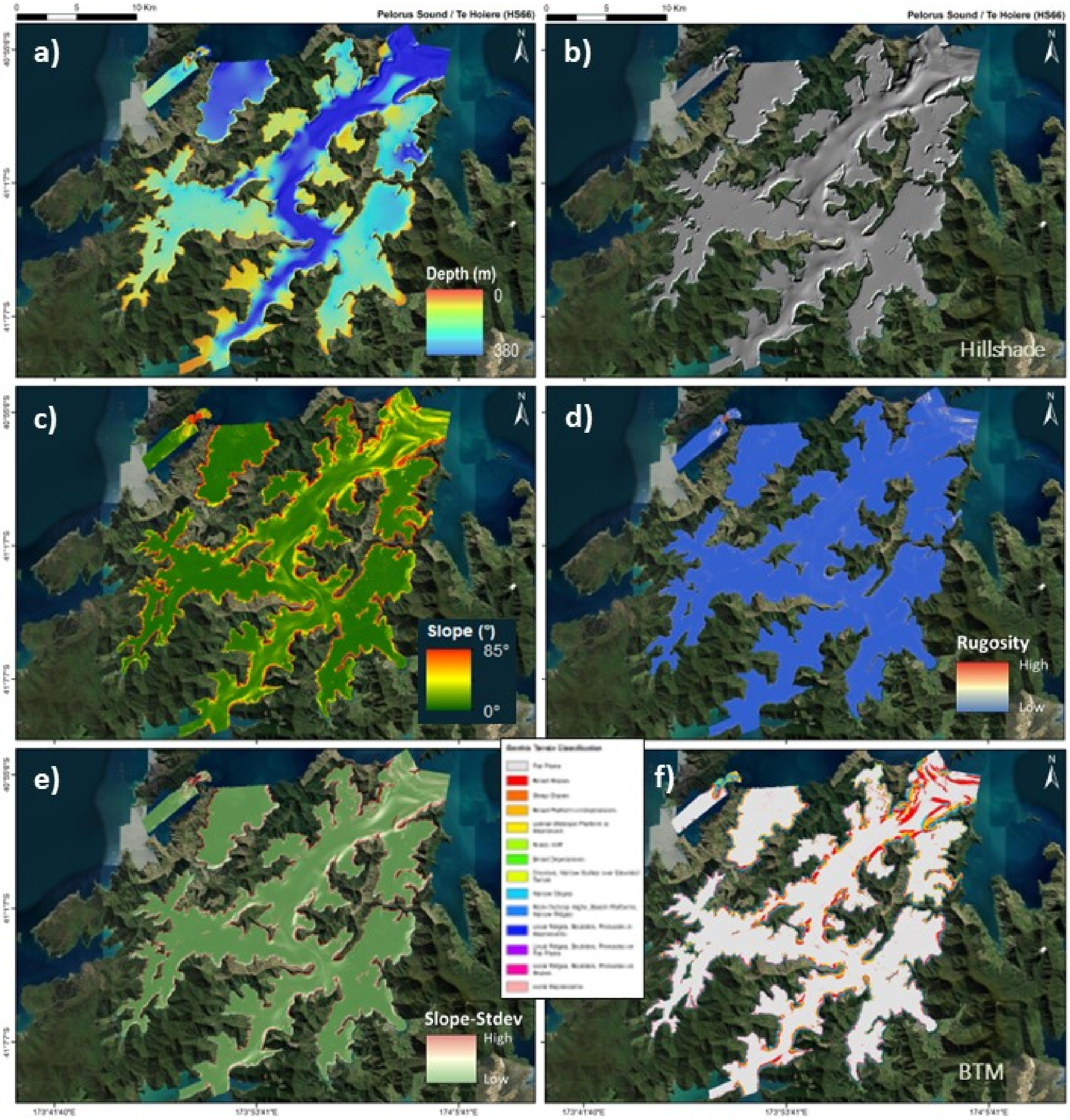

Figure 2. Examples of HS66 multibeam data layers (based on combined Kongsberg EM2040D and Reson SeaBat T50 bathymetry) across the extent of the 'western Marlborough Sounds' (HS66 survey). a) Bathymetry image (with sun-illuminated digital elevation model (DEM)); b) Backscatter; c) Slope terrain attribute; d) Seafloor rugosity (ruggedness of terrain: indicative of rocky ridges and reefs); e) Slope-standard deviation (indicative of rough seafloor, such as low-lying biogenic structure; shell-debris and cobbles and broken rubble); f) Benthic terrain model (BTM) classifications (seafloor geomorphology) generated from bathymetric data. Depths greater than 50 m are shaded blue to enhance more subtle nearshore depth changes.

3.1.1.2 Derived terrain attributes

The benthic terrain attributes (i.e., the bathymetry-derived raster layers) generated by Maier et al. (2021) for use in the benthic terrain modelling, were supplied via MDC as an ESRI file geodatabase, and ArcGIS project. These data layers were provided as 2 m raster layers, are examined here as part of this review. In addition, MDC GIS staff re-created six of those eight terrain attributes as per (Maier et al. 2021), but at 1 m horizontal resolution. This included a 1 m digital elevation model (DEM) of the HS66 bathymetry; and associated 'hillshade relief' with 3 times vertical exaggeration (with sun-illumination from the northwest 315° and altitude of 45+), as well as benthic terrain attributes (incl. slope, rugosity, aspect and curvature) that were each identical in all other aspects to Maier et al. (2021), following (Neil et al. 2018; examples in Figure 2). These dual resolution raster layers were preliminarily examined relative to other data layers to assess their relative value in predicting areas of significant marine biodiversity.

The standard deviation of the slope is a statistical measure that quantifies how much the slope differs from the mean slope of the surrounding area and was produced at 2 m resolution by Maier et al. (2021) during NIWA's Benthic Terrain Modelling. The 'standard deviation of the slope' layer (at fine scales) can provide extremely valuable information on the roughness of the seabed, and was found to be an invaluable layer during the ground truthing processes in the Eastern Sounds (albeit at the 2 m resolution): particularly in detecting and delineating biogenic habitats such as the bryozoan patch reefs at the entrance to Queen Charlotte Sounds (QCS) (Anderson et al. 2020b). High slope-stdev indicates that there is variation (which can infer low-relief roughness, where corresponding bathymetry and rugosity are not high). To examine the finer-scale value of this layer, a 1 m horizontal resolution standard deviation of the slope (hereon referred to as slope-stdev) was created (Figure 2e).

3.1.1.3 Rock outcrops layer

Rugosity of the seafloor was calculated by Maier et al. (2021) from the bathymetric surface for each 2m cell using the "Rugosity" function in Benthic Terrain Modeller toolbox (Jenness, 2004; Wright et al. 2005, 2012). This method uses a ratio of the surface (or contoured) area of the seafloor to planar area (straight line) across a square of 3 x 3 grid (i.e., 6 x 6 m area using the 2 m resolution bathymetric grid) (Figure 3a). Here, rugosity values near 1 = a smooth flat terrain, while higher values reflect increasing rugosity. Researcher divers on SCUBA used to measure rugosity manually by draping a chain over the seafloor and then measuring the chain length as a ration of the linear distance between the start and end point of the transect (e.g., McCormick, 1994). However, while this basic equation works fine if the seafloor is flat, when there is a slope, the equation gets confounded by slope angle (e.g., Figure 3b) as rugosity gets more convoluted. Improvements have led to an additional algorithm 'BTM's Arc-Cord Ratio method' (described in Du Preez, 2015), being added to the BTM package. Using the Arc-Cord Ratio method, rugosity of the surface is measured as the ratio between the contoured surface (the grey-dotted line in Figure 3b) and the 'plane of best fit' (the dashed line in Figure 3b), which enables the angle of the slope to be decoupled from the measurement of rugosity. The diver method only measured the ratio between 1 and 3 so this two-step method was never required (*see* McCormick, 1994). The BTM's Arc-Cord Ratio method and the diver-chain method are equivalent and measured over similar fine spatial resolution and as such should provide a realistic and biological-relevant scale of seafloor rugosity. No Information on which method was used to calculate rugosity for the HS66 survey was provided. Given most of the rugose habitat within the HS66 survey area is likely occurring on the narrow slopes that skirt the shores, the methodology used is likely important.

In addition to the BTM, Maier et al. (2021) created a 'Rock Outcrops' layer by combining four of the 14 BTM classifications together (Classes 10, 11, 12 and 13).

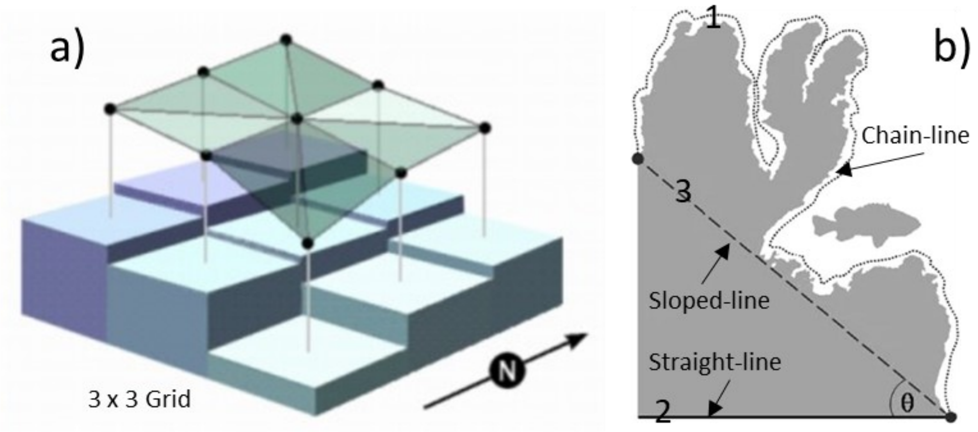

Figure 3. Illustrative example of how 'rugosity' of a bathymetric surface area is measured from an elevation grid (i.e., bathymetry) using the ArcGIS BTM toolbox. a) The three dimensional 3 x 3 grid surface area and the planar area of the surface used to calculate 'rugosity' within the BTM (*Reproduced from:* Jenness, 2004), and b) A real-world illustration of the rugosity of the surface area (here, an example of a coral reef) (*Reproduced with added labels from:* Du Preez, 2015). Here, rugosity of the surface is measured as the ratio between the contoured surface of the corals (dotted chain-line [1] = 11.2 m) and the planar distance (solid straight-line [2] = 2.58 m), giving a Rugosity Index of 4.31. However, here we see that the slope of the seabed inadvertently confounds this initial measure in the algorithm, so slope first needs to be decoupled, by, measuring and using the 'plane of best fit' (the dashed line [3] = 3.46 m) using BTM's Arc-Cord Ratio method (described in Du Preez, 2015). Noting here that the diver method measures the ratio between 1 and 3 automatically (*see* McCormick, 1994).

3.1.2 Backscatter

During the HS66-2020 MBES survey, iXblue preliminarily processed the backscatter from the four subregions they surveyed to create a preliminary (field -processed) seabed mosaic (i.e., French Pass, Admiralty Bay, North Pelorus and Popoure Reach). This was undertaken to help determine where to collect ground truthing sediment samples from (i.e., allocate sediment sampling across a range of sediment composition types) (Dave Field *pers. comm.*). This preliminary backscatter mosaic was provided by LINZ as geo-referenced tiff files (see Figure 4). No backscatter mosaic was rendered by DML for Pelorus South (i.e., the fifth survey area) (Figure 4).

Following the completion of the HS66 MBES survey, NIWA was contracted by LINZ and MDC through iXblue to:

(1) Assess the quality of the backscatter data to ensure that the backscatter response to the seabed was consistent across all depths, and between data acquisition systems; and was fit for scientific purpose (Mackay et al. 2020).

(2) Design and collect sediment grab samples and drop camera video footage from ground truthing sites across the HS66 survey area (Orpin et al. 2020).

3.1.2.1 Quality assessment of HS66 backscatter data:

NIWA QA/QC'd the backscatter data and created a preliminary backscatter mosaic using Fledermaus Geocoder Toolbox (FMGT) v7 QPS software[1]. All five subregions were imported into FMGT and then mosaiced together to examine the full backscatter surface for any irregular and unexplained changes in the backscatter signal that may be indicative of system errors (Mackay et al. 2020). To do this, HS66 raw backscatter time series files from the two backscatter data sources: Reson T50 (*.gsf files) and

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[1] FMGT (Fledermaus Geocoder Toolbox) is a backscatter processing tool created within the Center for Coastal and Ocean Mapping (CCOM) at the University of New Hampshire (UNH); but has now been created as a module within the commercial Fledermaus software from QPS (Lurton et al. 2015).

EM2040D (*.all files) were read in, along with the navigation files from each MBES line to create the port and starboard sides of each track-line. FMGT then provides a selection of algorithms to process backscatter from a wide range of sonars (including the Reson T50 and EM2040D). To assess the backscatter quality, Mackay et al. (2020) state that FMGT was used to perform some basic corrections to the backscatter signals, including[2]:

(1) **An 'Adjust' stage** – which performs "*some signal level adjustment due to range and transmission loss, beam incidence angle and beam footprint area adjustments*".

(2) **A 'Filter' stage**, which performs adjustments to the backscatter swath based on beam incidence angle and then performs an antialiasing pass (feathering algorithm smooths the edges) on the resulting swath backscatter data. It is unclear exactly what NIWA did in these 'basic' importing and processing (correction) steps, but it would be expected that Mackay et al. (2020) followed FMGT's basic methods and protocols, and the methods used by Neil et al. (2018) to enable comparability.

(3) **A 'Mosaicking' stage** – where the corrected backscatter files are mosaicked together to create a 2-dimensional backscatter image of the seafloor (grey-scale image). The key here is that mosaiced image was then carefully examined for completeness and any signs of systematic errors (e.g., striping, gradual power loss or missing pings). Mackay et al. (2020) stated that while some minor holes were seen, these were not significant and nothing worth going back to fix. Mackay et al. (2020) then stated that the backscatter data were of good quality and fit for scientific purpose. However, no raster, or georeferenced image, of this '*preliminarily*' seabed backscatter mosaic was supplied to MDC/LINZ.

3.1.2.2 Seafloor Reflectivity Classification (SRC)

Following the quality assessment of the raw seafloor backscatter data, NIWA created a provisional training dataset by splitting the 'unprocessed'[3] backscatter data into four backscatter reflectivity classes (see Table 1). The four Seafloor Reflectivity Classification (SRC) categories used for the HS66 were based on the same four categories mapped over the HS51 survey area, and that were validated by a subset of the HS51 ground truthing data (Neil et al. 2018). In the initial HS51 mapping programme, a supervised segmentation (partitioning) classification approach was employed, where 66% (n=~82) of the HS51 ground truthing sites were used to train the relationship between the mean grain size values and the backscatter reflectivity (dB) values, while the remaining 33% (n=~41) of the ground truthing sites were used to test the validity of this relationship: i.e., between backscatter reflectivity (dB) values at these sites and their mean grain size (Neil et al. 2018). In this training and validation approach, sites where rock outcrops were identified in the dropcam video footage were assigned grain-size values commensurate with gravel to ensure hard sediments, which cannot be sampled by grabs, were also adequately modelled (and validated) in the SRC data layer. Given the similarities between the Eastern (HS51 survey area) and the Western (HS66 survey area) Sounds, this classification of the new HS66 backscatter reflectivity data into the four SRC categories (*as presented in Figure 5-3 of* Orpin et al. 2020; and shown here in Figure 5) was used to allocate new HS66 ground truthing sampling effort (Table 1), which in turn could be used to validate this SRC approach for the new HS66 region. Importantly, Mackay et al. (2020) stresses that the use of this provisional SRC layer "*does not circumvent or replace the need to fully process the [HS66] backscatter data*".

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[2] FMGT, under automatic mosaicking, runs a pipeline of corrections designed to perform as many corrections as possible to maximise the information content of the backscatter signals, which can also be adjusted under manual mosaicking.

[3] Although it is stated that the unprocessed backscatter data was used to create the SRC layer, it is likely FMGT mosaicked data was used, and if so, this mosaiced data layer would represent some level of 'minor' processing basic corrections and cleaning to the backscatter signals (Mackay et al. 2020; Orpin et al. 2020), although this was not clearly described.

Table 1. NIWA's Seafloor Reflectivity Classification (SRC) categories from Orpin et al. (2020).

SR Class	HS66-2020 sediment samples[1]	Reflectivity level	Backscatter data range (dB)	Sediment description/characterisation
1	27 (20%)	Low	< -22	Homogeneous, corresponding to mud (silt and clay). These sediments absorb most of the acoustic energy due to high water content and small particle size.
2	23 (17%)	Low-medium	-22 to -18	Homogeneous, corresponding to fine sandy seafloor sediments Sandy sediments refract and absorb some of the acoustic energy
3	24 (18%)	Medium-high	-18 to-14	Homogeneous, corresponding to medium sandy substrates (as well as hard substrate or bioturbated sediments).
4	59 (44%)	High	> -14	Highly heterogeneous, corresponding to substrates with coarse sands, shell-debris and/or gravels, or rock (i.e., where high reflectivity and high rugosity scatters incident energy, resulting in high backscatter variance).

[1] No. of HS66 sediment grab samples assigned to each seafloor reflectivity class, to validate the model application to this new area. Noting that no training data from the HS66 region was used in the model creation.

The methods outlined Orpin et al. (2020), report that the sampling effort for the HS66-2020 ground truthing campaign was allocated between the four SRC classes to ensure that higher reflectivity classes that represent more variable and diverse textural substrates (e.g., mixtures of sands, shell and gravel[4]), but often have limited spatial cover, were adequately sampled. Unlike a 'randomly allocated sampling design' this approach ensured that these higher-reflectivity spatially-limited substrates were not missed or inadequately sampled.

This method ensured that more grab samples were collected within the higher reflectivity classes (which were less spatially prevalent), as a way of capturing the higher variability (reflectivity variance) in these classes. However, this meant that the low reflectivity class inferring 'homogeneous muds' that occurred far more extensively across the region were allocated much fewer samples (proportionally, relative to the area occupied in the SRC map). This approach was taken to ensure that diverse substrates were adequately sampled/ground truthed, but it does assume that low reflectivity classes are always homogenous, which may not always be the case (in terms of biology). Given the extensive predicted area of this low-reflectivity category, this low sampling effort might be too low to adequately test this assumption. However, this assumption could be tested by examining the variance in backscatter reflectivity within this category, across the extent of its' spatial distribution.

The SRC raster (data) layer presented in *Figure 5-3 of* Orpin et al. (2020) was not provided to MDC, or at least, was not available for this review. To examine the relationship between this SRC layer and other MBES layers and the newly collected HS66-2020 ground truthing sites and habitat descriptions, the SRC image from *Figure 5-3 of* Orpin et al. (2020) was geo-rectified and plotted in ArcGIS (Figure 5) to examine how well the HS66 ground truthing data correlated with this SRC layer.

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[4] Gravel here also includes hard substrata

3.1.3 Sediment grain size

To characterise the sediment types, sediment grain size and to ground truth MBES layers, particularly the Seafloor Reflectivity Classification categories, 183 sediment grabs samples were collected from 182 sites across the spatial extent of the MBES-HS66 survey area. (*See* Table 2, *for splits by subregion*; and Figure 6 *for grab sample locations*). Specifically:

1. DML collected 16 grab samples, using a Van Veen Grab, from Pelorus South (*site locations are shown as purple triangles in* Figure 6). Each sample was photographed, described, and a grain-size subsample retained, refrigerated then delivered to NIWA (Discovery Marine Ltd. 2020).
2. iXblue collected 31 grab samples during February 2020, using a Mini Van Veen sampler, across the other four subregions: French Pass and Admiralty Bay, Pelorus North, and Popoure Reach) (*site locations are shown as yellow triangles in* Figure 6). Each sample was photographed, described, and a grain-size subsample retained, refrigerated then delivered to NIWA (IXblue 2020).
3. NIWA collected 135 grab samples (from 134 sites), using either a Dietz-Lafond or a Van Veen grabs (*site locations are shown as red triangles in* Figure 6). Here samples were allocated to the four-seafloor reflectivity classes (Orpin et al. 2020; see Table 1).

Sediment samples collected at all sites, by each of the three surveyors, were all described based on international hydrographic survey standards (*defined in* Table 3) and photographed. All sediment samples were provided to NIWA for storage and further processing. Photographs of grab samples collected by DML and iXblue surveys were all provided as part of this review, but only the few selected grab and video-still site photos published in Orpin et al. (2020) were available from the NIWA survey. Detailed descriptions of all samples are provided in the Appendices of Orpin et al. (2020). This review utilises the detailed seafloor and sediment descriptions presented for each site (based on the Appendices of Orpin et al. (2020) and sediment photographs from DML and iXblue surveys, to characterised substratum type, as a preliminary step to evaluate/ground truth the MBES layers and the SRC layer (details of this approach are provided below, in Section 3.2.1).

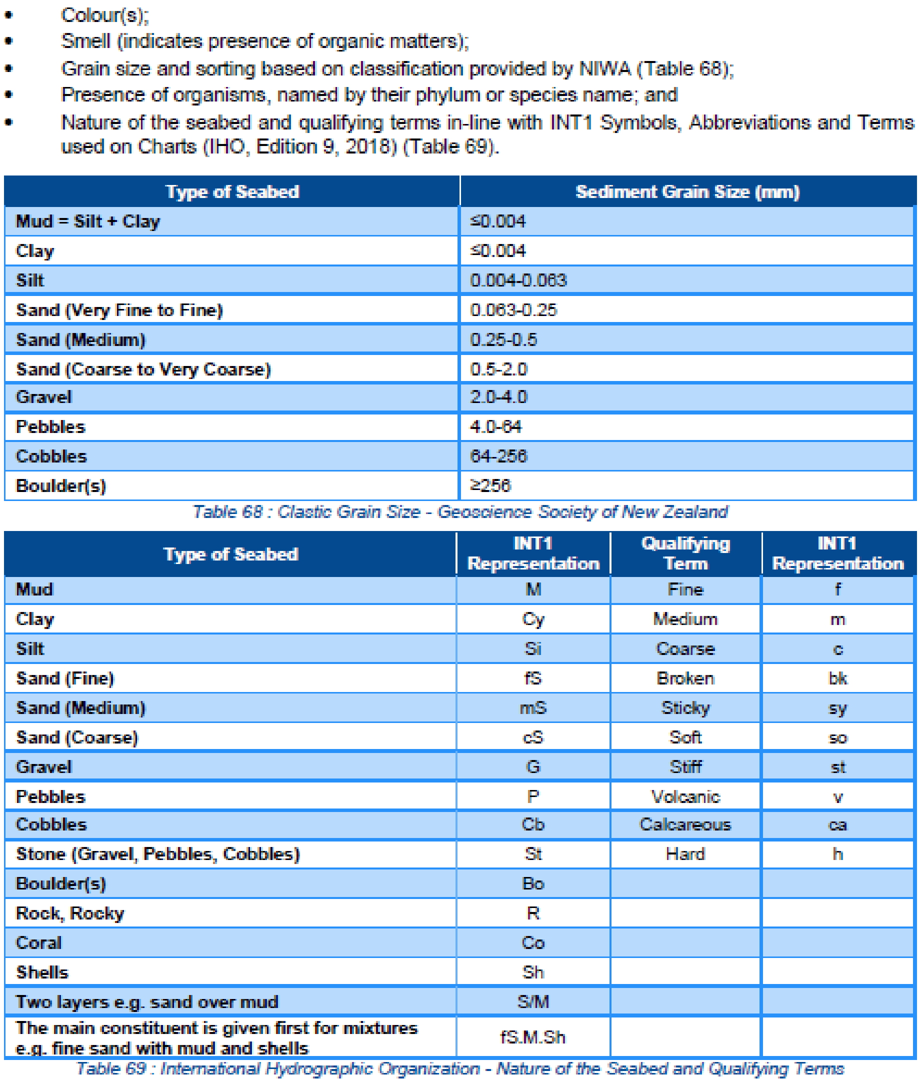
Table 2. Number of sediment grab samples collected by region Total grab samples: values are the combined samples collected by DML, iXblue and NIWA during the HS66-2020 ground truthing campaign; (%values) are the percent of samples collected by NIWA (which were allocated relative to the four SRC).

Subregion	**Sediment grab sites** No. (% of total)	**Grab sites coll. by NIWA** No. (% by region)	**Grab sites paired with NIWA's dropcam** No. (% by region)
French Pass	10 (5%)	5 (50%)	5 (50%)
Admiralty Bay	13 (7%[1])	9 (69%)	8 (61%)
Pelorus North	57 (31%[2])	46 (81%[2])	42 (74%)
Pelorus South	66 (36%)	49 (74%)	48 (73%)
Popoure Reach	36 (20%)	26 (72%)	26 (72%)
Grand Total	***n =183***	**n = 135 *(74%)***	**n= 129 *(71%)***

[1] One sample (DML grab sample G06) was collected from the French Pass region, but lay outside the HS66 survey area. This grab sample was collected from Coppermine Bay in 5 m water depth in the ESMS-1.5 designated area around a dense rhodolith bed (see Clark et al. 2022); the location of this area is indicated *in* Figure 44a-d *as pink dotted lines & the letter R*).

[2] Sediment grab sample NIWA Site 'PS-ENT-REEF' was recorded with an incorrect longitude entry (-40.9257, ~~170.0278~~) that was able to be corrected using the paired dropcam GPS location (-40.9257, 174.0278).

Table 3. Sediment descriptions recorded for each sediment grab sample collected during the HS66-2020 ground truthing campaign, by each of the three survey teams (IXblue, DML and NIWA). Descriptions follow the International Hydrographic standards (*represented here from Tables 68 and 69 of* IXblue, 2020 p113).



- Colour(s);
- Smell (indicates presence of organic matters);
- Grain size and sorting based on classification provided by NIWA (Table 68);
- Presence of organisms, named by their phylum or species name; and
- Nature of the seabed and qualifying terms in-line with INT1 Symbols, Abbreviations and Terms used on Charts (IHO, Edition 9, 2018) (Table 69).

Type of Seabed	Sediment Grain Size (mm)
Mud = Silt + Clay	≤0.004
Clay	≤0.004
Silt	0.004-0.063
Sand (Very Fine to Fine)	0.063-0.25
Sand (Medium)	0.25-0.5
Sand (Coarse to Very Coarse)	0.5-2.0
Gravel	2.0-4.0
Pebbles	4.0-64
Cobbles	64-256
Boulder(s)	≥256

Table 68 : Clastic Grain Size - Geoscience Society of New Zealand

Type of Seabed	INT1 Representation	Qualifying Term	INT1 Representation
Mud	M	Fine	f
Clay	Cy	Medium	m
Silt	Si	Coarse	c
Sand (Fine)	fS	Broken	bk
Sand (Medium)	mS	Sticky	sy
Sand (Coarse)	cS	Soft	so
Gravel	G	Stiff	st
Pebbles	P	Volcanic	v
Cobbles	Cb	Calcareous	ca
Stone (Gravel, Pebbles, Cobbles)	St	Hard	h
Boulder(s)	Bo		
Rock, Rocky	R		
Coral	Co		
Shells	Sh		
Two layers e.g. sand over mud	S/M		
The main constituent is given first for mixtures e.g. fine sand with mud and shells	fS.M.Sh		

Table 69 : International Hydrographic Organization - Nature of the Seabed and Qualifying Terms

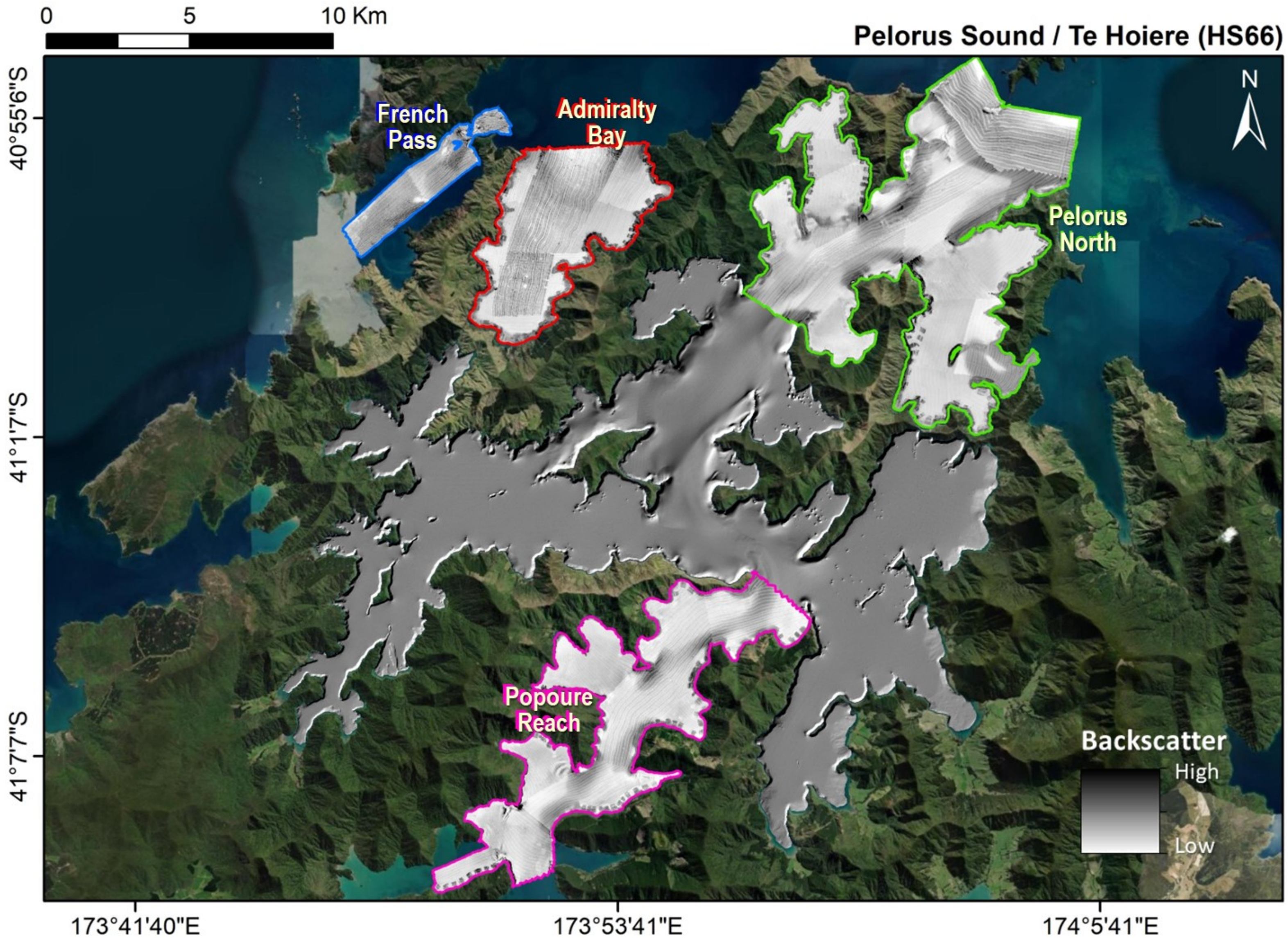


Figure 4. Preliminary HS66 backscatter processed by iXblue for the four regions they surveyed (i.e., French Pass, Admiralty Bay, North Pelorus and Popoure Reach). Here, backscatter was processed to determine where to take ground truthing sediment samples. No backscatter was processed for South Pelorus.

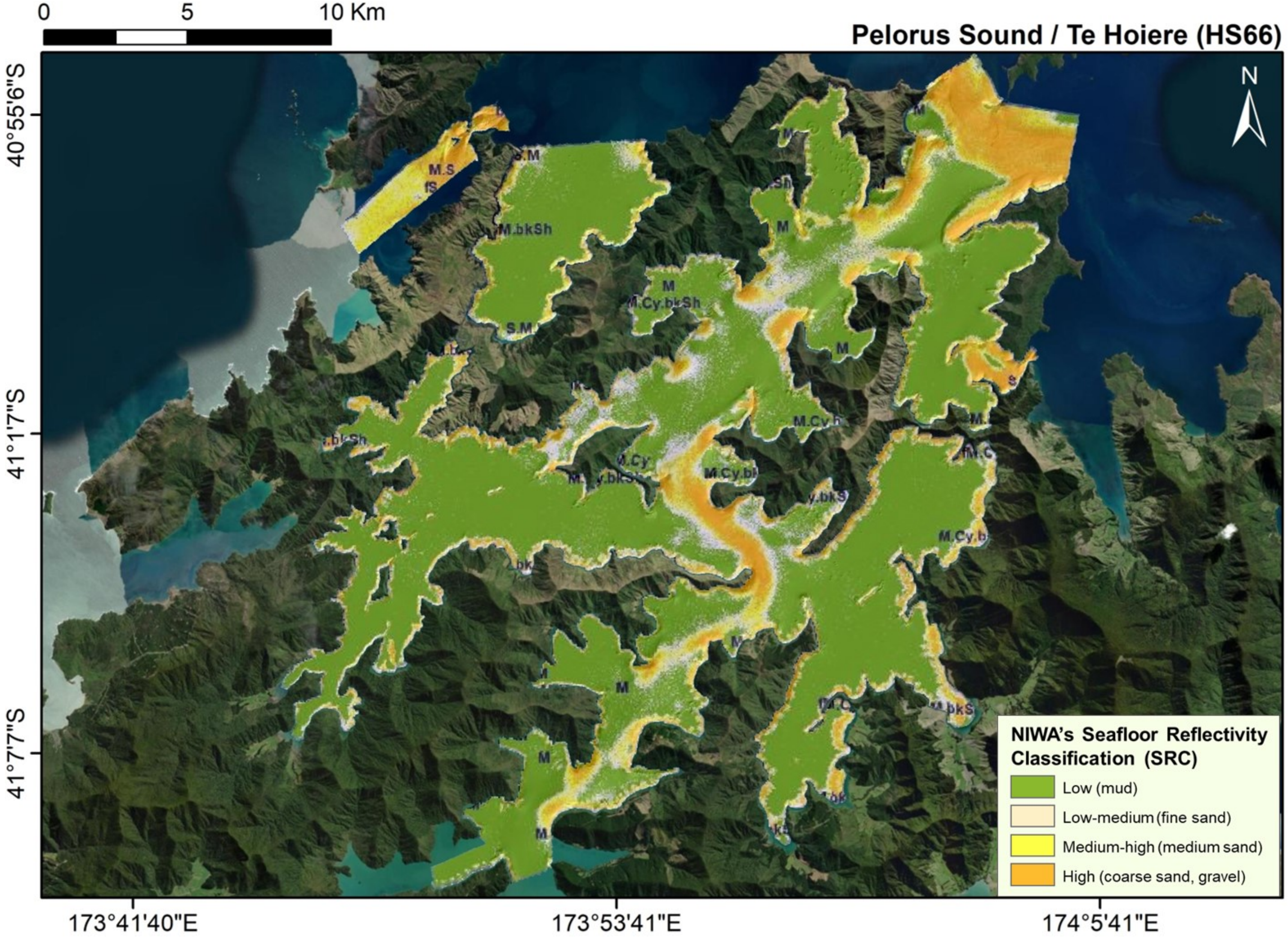


Figure 5. Geo-rectified image of NIWA's preliminary seafloor reflectivity classifications (SRC) for the HS66 survey. Drawn from unprocessed and uncalibrated backscatter data, used to aid field selection of seafloor ground-truthing sites (refer to Appendix A-C in Orpin et al. 2020; and methods outlined in Neil et al. 2018).

3.1.4 Water column

Water column data for the entire HS66 survey area was collected as part of the MBES-HS66 survey. Mackay et al. (2020) provides a brief overview of data quality checks that were undertaken to verify these data as fit for scientific purpose. Here, like backscatter from the seafloor, the strength of the return signal from the section of water column before it reaches the seafloor (or water-column data), can be used to detect objects (and/or biota) present in the water column (Colbo et al. 2014). During the HS51 survey, this approach was evaluated, and in one example, at one offshore Cook Strait site was even able to detect and map the water column position of the vertically hanging rope from a lost cray pot (T. J. Anderson, Stewart, et al. 2020). Water column backscatter is considered the 'third data type' of new MBES systems (where bathymetry and seafloor backscatter are the first two). However, the detection and processing methods used to examine these data are relatively new to seafloor mapping, and are still evolving methodologies to more accurately detect and map benthic biota, such as macroalgae growing above (e.g., *Macrocystis*), while species growing closer to the seafloor (e.g., *Ecklonia*) are still difficult to accurately discern (Schimel et al. 2020).

Survey protocols for all backscatter data (seafloor and water column data), which are briefly described in Mackay et al. (2020), were set to ensure "*consistent backscatter response to the seabed and water column across all depths*". Water-column data from both surveyors (logged as *.wcd files) were regularly checked by NIWA backscatter experts during the surveys to ensure high-quality fit-for-purpose backscatter data were being collected. After these surveys were completed, all water-column data was screened and checked as part of the seafloor and water-column QA/QC contract. This QA/QC assessment of the water column data identified that for some lines water-column data were not fully recorded (Mackay et al. 2020), however, no clarification was provided as to which lines these were or what "fully" pertained to. Overall, however, Mackay et al. (2020) reported that ~99.6% of the HS66 survey area had accompanying water-column data that was "fit for scientific purpose", and that the missing water-column data was inconsequential when weighed against the additional resourcing costs that would be required to fill-in these missing segments.

3.1.5 Near-bottom current speeds

In 2015, MDC funded NIWA scientists (Broekhuizen et al. 2015) to create a biophysical model for the Pelorus Sounds that provides useful insight into the process shaping the benthic environment within Pelorus Sounds. This research was undertaken prior to the high resolution HS66 bathymetry being collected, and so is based on ROMS (Regional Ocean Model) hydrodynamic model using much coarser bathymetry (Broekhuizen et al. 2015). Bathymetry for the hydrodynamic current model was constructed from the amalgamation of a digital terrain model, gridded at 25 m resolution, contour data (digitised by NIWA from LINZ charts), and high-resolution coastline data (to fix the zero contour in the model) (Broekhuizen et al. 2015, p18). This was then used to create a 3-dimensional biophysical model that consisted of 20 layers in the vertical, 200 m in the horizontal, and was coupled to a biogeochemical model, where simulations spanned 500 days with outputs of the model validated with field collected data from MDC (see Broekhuizen et al. 2015 for specific details).

As part of this review, the 'near-bottom current speed' for both the HS66 survey area (Broekhuizen et al. 2015) and, for comparison, the HS51 survey area (Hadfield et al. 2014) are examined here. The model output from (Broekhuizen, Hadfield et al. 2015) for '*mean current speed at 5 m depth'* was exported from the model as an "*.nc" file and imported and converted into an NetCDF raster file in ArcGIS. The near-bottom current speed layer was then plotted in ArcGIS, projected to NZTM and clipped by the MBES-HS66 coverage area. This layer was then examined relative to MBES layers and available ground truthing data.

3.2 Ground truthing (what's available)

3.2.1 HS66-2020 ground truthing campaign

During the HS66 multibeam mapping surveys, DML, IXblue, and NIWA surveyed a combined total of 218 ground truthing sites using sediment grabs (Figure 6) and/or dropcam video (Figure 7). Specifically:

1. On the 7-8th February 2020, iXblue collected a single sediment grab sample from 31 sites, using a Mini Van Veen sampler. Sites were allocated across the four of the MBES survey subregions (yellow triangles in Figure 6), based on examination of the preliminary (field-processed) backscatter. This resulted in a total of 5 sites sampled in French Pass, 4 in Admiralty Bay, 11 in Pelorus North, 10 in Popoure Reach and one in Picnic Bay (IXblue 2020). Detailed descriptions of the sediments collected at each of these site (labelled G01 to G50) are provided in Appendix B of Orpin et al. (2020); with iXblue sediment samples retained by National Institute of Water and Atmospheric Research Limited (NIWA) for curation.
2. In March 2020, Discovery Marine Ltd. (DML) collected a single sediment grab (only) sample from an additional 16 sites within Pelorus South (the fifth of the five subregions), using a Van Veen Grab (purple triangles in Figure 6; Discovery Marine Ltd., 2020). Detailed descriptions of the sediments collected at each of these site (labelled SS-003 to SS-020) are also provided in Appendix B of Orpin et al. (2020); with DML sediment samples retained by National Institute of Water and Atmospheric Research Limited (NIWA) for curation.
3. In July 2020, NIWA undertook a ground truthing survey across the entire HS66 survey region (all five subregions), collecting sediment grab samples from an additional 135 sites, using a Dietz-Lafond (clam-shell) or Van Veen grab (red triangles in Figure 6; Orpin et al. 2020). Detailed descriptions of these samples are provided in Appendix A of (Orpin et al. 2020). Grab sampling data were combined with iXblue and DML resulting in a total of 183 grabs from 182 sites within the HS66 survey area.

   NIWA also collected drop-camera footage (seconds to minutes) of the seafloor from 165 video sites (Figure 7), using NIWA's CoastCam and CBed towed camera system, including footage of the seafloor at most grab site (Orpin et al. 2020). Of these 129 were paired with grab-sampling sites, while 36 dropcam sites sampled harder habitat types (e.g., rock) that grabs could not sample.

CBed classifications: Using the ground truthing information provided in the Appendices A-C in Orpin et al. (2020), the seafloor descriptions from the sediment grab sampling and the dropcam video footage were integrated to provide a single seafloor habitat classification for each site. To do this, each site was broadly characterised by its primary (1°) and secondary (2°) substratum types (*based on CBed-classification scheme of* Anderson et al. 2007; Nichol et al. 2009). For example, a seafloor site that was mostly mud with shells was classified as 1° = mud and 2° = shells. Similarly, a site dominated by rocks with some cobbles was classified as 1° = rock and 2° = cobbles. Annotated descriptions of key taxa in Orpin et al. (2020) were also transcribed as presence or absence to provide some additional spatial discrimination. Some site corrections were required, as several of the GPS locations from the dropcam sites erroneously plotted over land, however, these were able to corrected using the paired grab site position. This new combined classification table was then imported into ArcGIS, as a shapefile with a NZTM projection, and plotted over the MBES data layers.

3.2.2 Other recent benthic video surveys (>2010)

In the autumn of 2107, NIWA researchers, led by Tara Anderson, undertook an extensive benthic dual-gear survey across the Marlborough Sounds as part of the MBIE-funded 'Juvenile fish habitat bottlenecks' Endeavour programme (C01X1618), aimed at discovering the location and habitat characteristics of blue cod nursery habitats within the Sounds (Anderson et al. 2019; Anderson et al. *in prep.*). Of the 393 sites (216 beam-trawl sites, and 177 tow-video sites) that were surveyed across the broader sounds, 72 sites (45 beam trawl sites and 27 tow-video sites) were surveyed within the HS66 region (Figure 8). Beam trawl sites (orange circles in Figure 8, BT17), were surveyed in trawlable habitats using a small custom-built 3-m beam trawl (Anderson et al. 2019), with GoPro video cameras attached to the spreader-bar to video seafloor habitats. At each tow-video site (yellow circles in Figure 8, CB17), a c. 10-min long video-transect was run using NIWA's CBedcam (Anderson et al. 2019). The beam trawl GoPro cameras were limited to available natural light, and therefore impeded by depth/water clarity, particularly within the inner Sounds (pers. obs.); however, the tow-video system, with its high-intensity lights, provided excellent imagery at most sites (Figure 8).

MPI blue cod potting surveys, undertaken by NIWA within the Marlborough Sounds includes GoPro cameras within Pots and in 2010 a drift video survey was undertaken (*see* Beentjes and Carbines, 2012a). In the drift video survey, video transects were 'partitioned into gross general benthic habitat sections' and then later the seafloor habitats were recorded with independent quadrats along each transect by i) primary substrate (e.g., sand, bedrock, etc.), ii) secondary habitat structure (e.g., macro-algae, sponge, shells); iii) percentage cover, iv) topographic complexity (four categories), and v) actual counts of blue cod, and other benthic species where possible (*see* Beentjes and Carbines, 2012a p13). Site metadata for the MPI temporal potting surveys along with the years sampled are provided in NIWA's survey and stock assessment reports (e.g., (MP Beentjes et al. 2012; Beentjes et al. 2017)). In 2013, several potting locations were also mapped using NIWA's multibeam Approximately 22 potting sites have were surveyed within the HS66 survey area. The underlying fish-habitat data for these surveys is held by Fisheries New Zealand (FNZ).

Cawthron has undertaken a wide range of benthic surveys within the Marlborough Sounds in recent years (≥ 2010), including the collection of video footage from both dive and tow-video surveys, resulting in at least 125 sites where benthic video footage has been collected (Figure 9). Many of these surveys have been associated with baseline and monitoring surveys around existing marine farms (e.g., Waitata and Richmond Bay Salmon farms, and their associated control/reference sites e.g., Ketu Bay and Treble Point (Atalah et al. 2011b); as well as assessments of other potential sites for marine farms (e.g., Kaitira (Atalah et al. 2011a); and other ecological studies.

Other known benthic surveys completed since 2010, that would be valuable contributions to the ground truthing planning and map verification are Morrisey et al. (2015) and Brown et al. (2016) and other Cawthron surveys, and any other recent benthic surveys particularly where video footage of the seabed has been spatial recorded, and where these reports are published and/or publicly available. Both Morrisey et al. (2015) and Brown et al. (2016) undertook a series of extensive baseline surveys of potential new salmon marine farm sites in 2013-14 and 2014-15 respectively. Habitat and biological descriptions from these surveys (presented by site) are provided in their respective reports, along with GPS positions of all sites in their appendices. For example, Appendix G in Morrisey et al. (2015) provides GPS positions, depth and habitat descriptions of drop-camera sites that were surveyed at each farm and control location within Pelorus Sounds / Te Hoiere. These can easily be included in the available ground truthing descriptions.

These benthic survey data with site descriptions since-2010, provide valuable ground truthing information. Collating this data can help 'evaluate' map predictions/inferences, identify where useful samples already exist, and importantly contribute to verifying important habitats and community types within the HS66 survey area – relative to the seafloor MBES map layers. This existing data is also valuable to help extrapolate similar seafloor information relative to this known (ground truthed) biodiversity, across the rest of the map – prior to new data being collected.

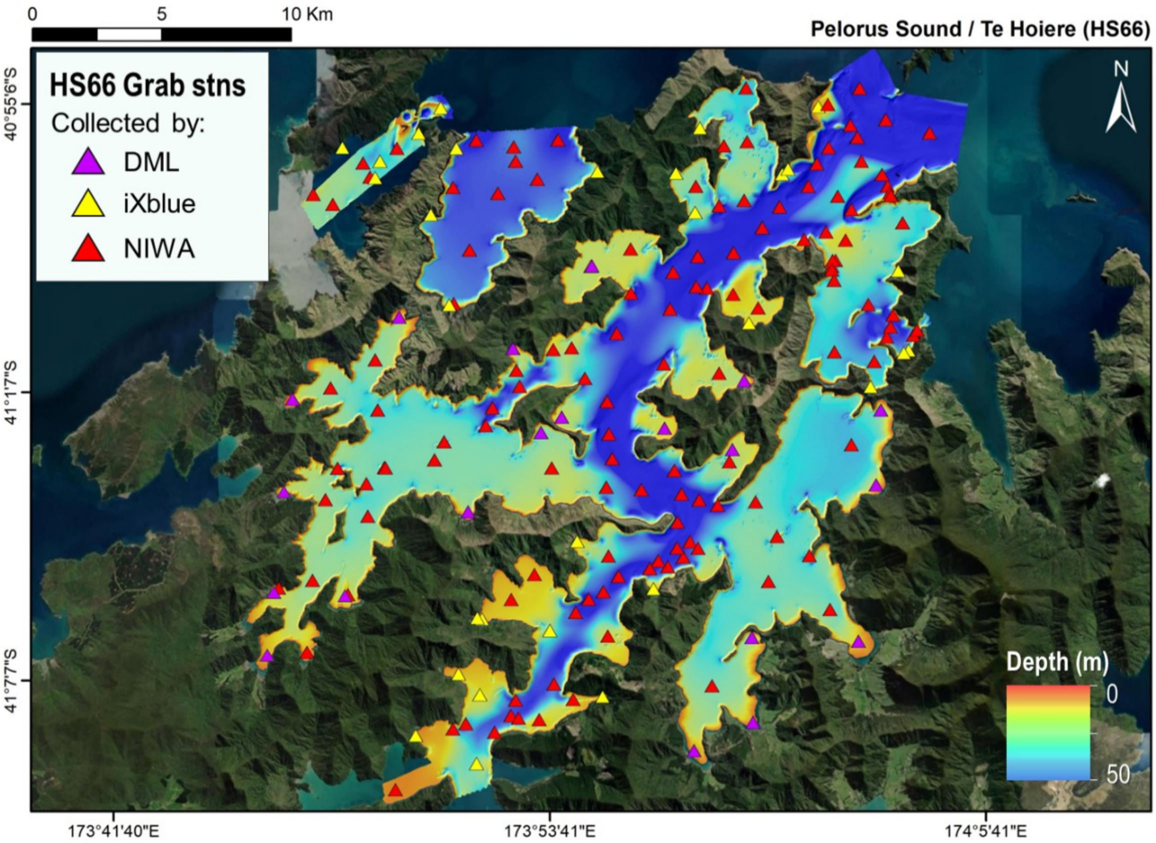


Figure 6. Location of HS66 sediment samples collected by DML, iXblue and NIWA, overlaid on the Multibeam bathymetry. Sample locations from Appendix A-B in Orpin et al (2020).

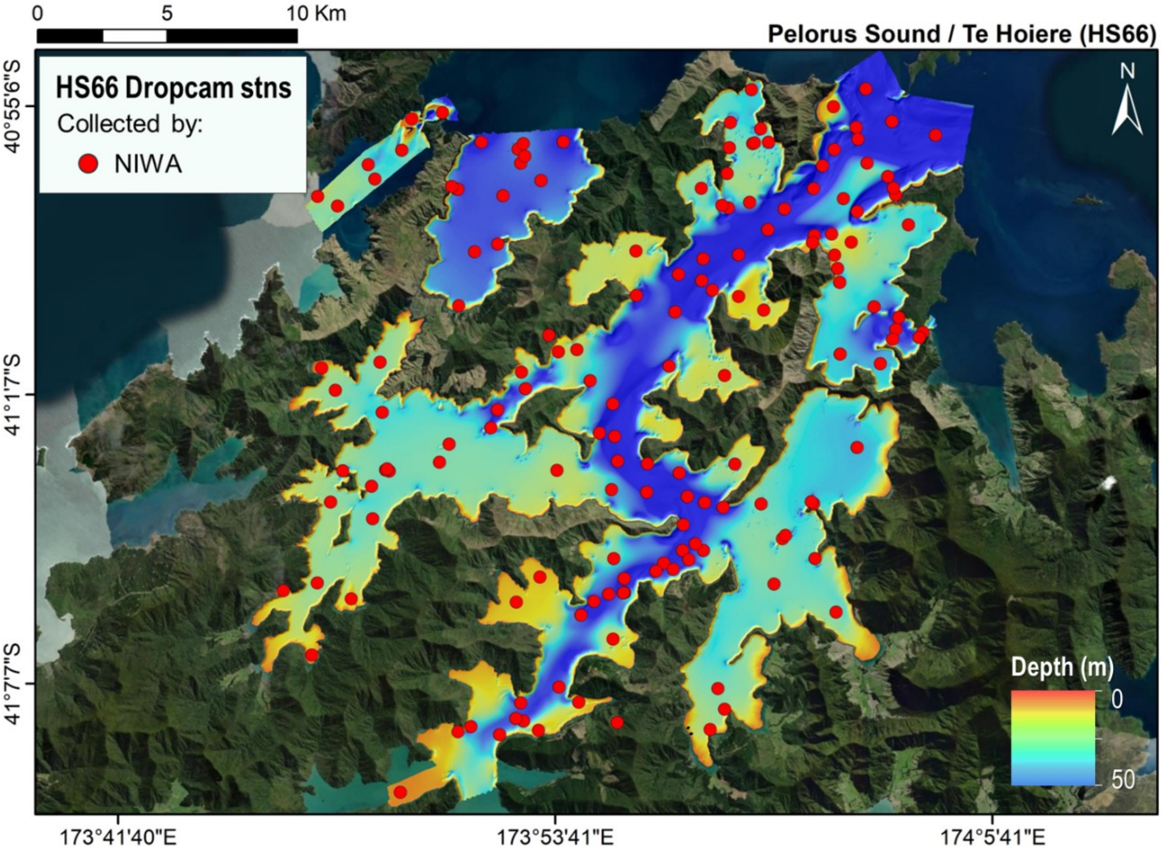


Figure 7. Location of HS66 dropcam video sites collected by NIWA, overlaid on the multibeam bathymetry. Sample locations from Appendix C in Orpin et al (2020).

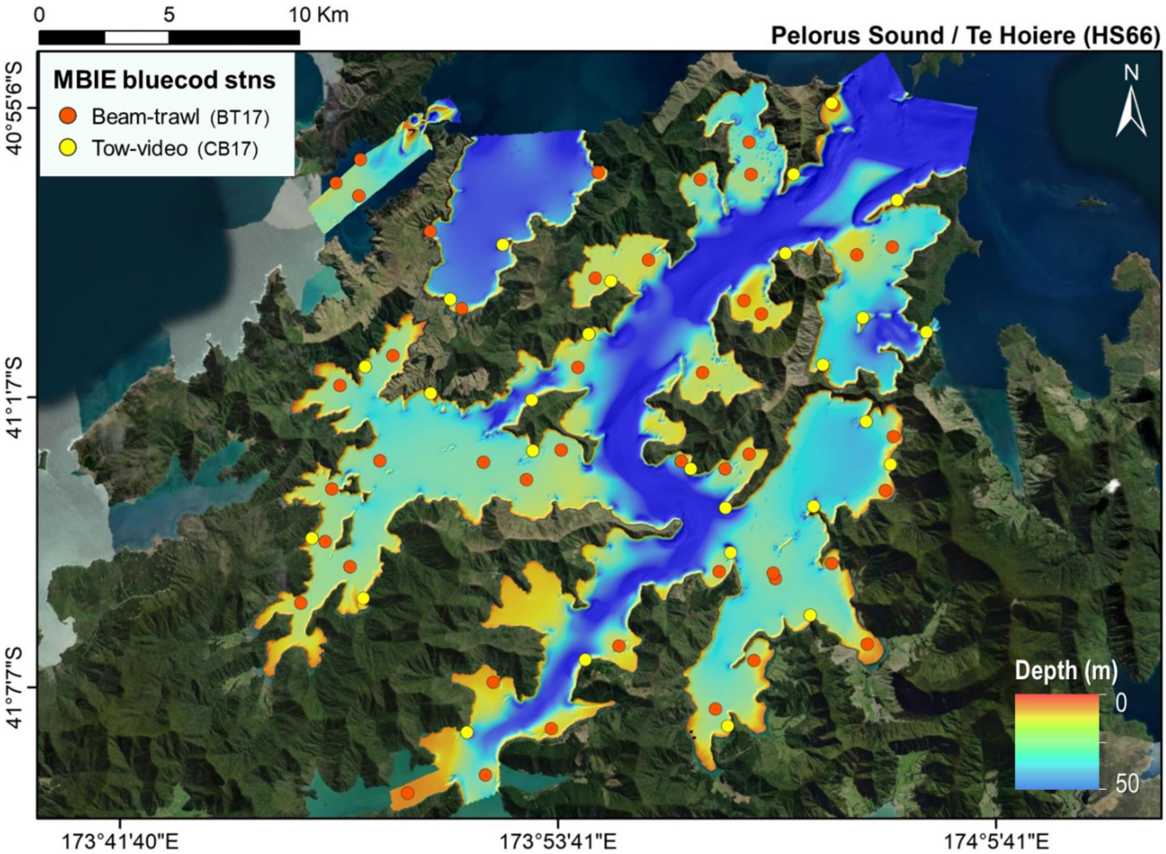


Figure 8. Beam trawl and tow-video site locations from the MBIE-funded 'Bottlenecks programme' (C01X1618), within the HS66 survey area. Orange circles (and labels) = beam trawl sites; Yellow circles (and labels) = Tow-video sites. (Published survey sites from Anderson et al. 2019)

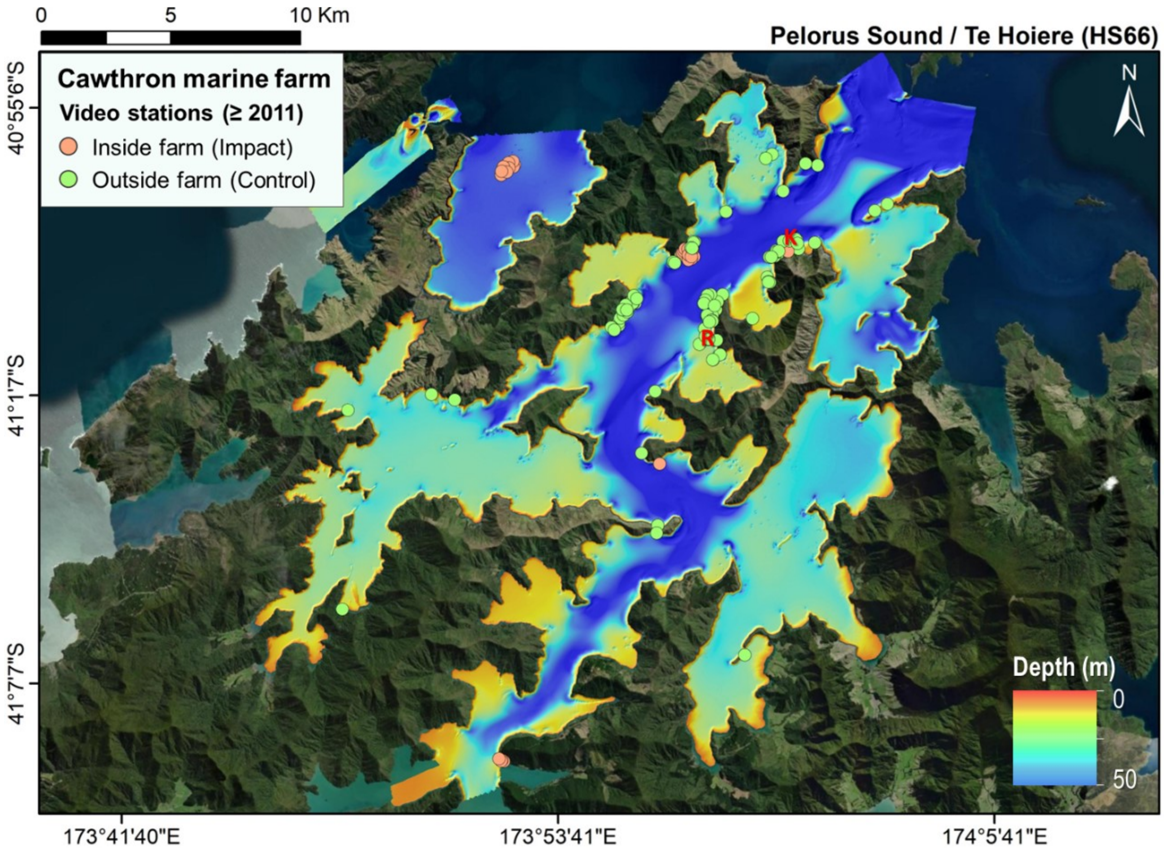


Figure 9. Location of Cawthron's benthic-video sites (surveyed from 2011 onwards) within the HS66 survey area. K and R = the location of Kaitira (an assessed site); and Richmond (a salmon farm site) that are examined in more detail in Figure 27 and Figure 28, respectively.

3.2.3 Historical information (<2010)

3.2.3.1 Benthic ecological surveys (<2010)

A variety of other benthic survey data has also been collected within the HS66 survey area prior to 2010, with some undertaken over half a century ago. Some of these surveys have been well documented in reports and publications (including the addition of site GPS positions), while others have not. Collation of historical and recent benthic survey information is an important step in planning ground truthing surveys to ensure that new sampling effort is allocated wisely, and makes use of existing information. As part of this review some of these historical site records (where available) have been collated to examine relative to the MBES layers. Other known benthic surveys/datasets that may be accessible have also been reviewed to determine their potential value.

Although Dell (1951) collected benthic samples within the Marlborough Sounds, none were collected from within the HS66 survey area. However, Estcourt (1967) reported the distribution of benthic macro-infaunal invertebrates in the Marlborough Sounds from c. 60 sediment grab sites, with 27 of these sites sampled within the HS66 survey area (see: Figure 10). A range of benthic specimens from Estcourt's (1967) survey were also submitted to Museum/specimen collections. McKnight (1969) described infaunal benthic communities from > 600 benthic samples around New Zealand’s continental shelf, but this also included some sites within the Sounds (details provided in the Appendix, (McKnight 1969). During the 1980’s Dr Cameron Hay lead a DSIR dredge survey across the Marlborough Sounds to look for horse mussels (*Atrina zelandica,* hereafter referred to as *Atrina*) as part of an exploration into the fishery potential of *Atrina* (C. Hay, *pers. comm.*). In addition to the broad scale dredge survey, Cameron Hay and his colleagues undertook a series of diver surveys examining the density (dive transects) and health (morphometrics from c. 10-20 specimens) of horse mussel beds through time (C. Hay, pers. comm.). The location of the dredge sites (and some scuba sites) with reported habitat and community composition, is published in (McKnight, 1969; McKnight et al. 1991b) (Figure 10).

In the summer of 1989-1990, an extensive snorkelling and diving survey led by Clinton Duffy was undertaken to document the types of benthic habitats present in depths < 20 m (Duffy et al. unpublished data; R. Davidson, pers. comm.; see digitised site map in Figure 11). Although significant habitats and communities discovered during these initial surveys have been reported in MDC significant sites reports (e.g., Davidson et al. 2011; 2015; 2021), site-specific habitat and community details have remained unpublished. Sites deemed to support significant biogenic habitats and communities have been examined in more detail and sites delineated to some level by subsequent surveys undertaken on behalf of MDC (e.g., Davidson et al. 2010, 2011, 2020)

Another extensive source of information is the compilation of baseline and monitoring marine farm surveys, undertaken since the onset of marine farming began in the Sounds. Many marine farms have had multiple spatial and temporal surveys undertaken for various resource consent needs, including habitat assessments; sediment grain size analyses; and various levels of benthic ecological assessment - with some sites also being intensely surveyed (e.g., Morrisey et al. 2015; Brown et al. 2016) with localised habitat maps created (e.g., Richmond Salmon Farm along Waitata Reach, Atalah et al. 2011b), while others have been mapped and surveyed, but were never farmed (e.g., Kaitira, Atalah et al. 2011a). Marine farms surveyed within the Marlborough Sounds under the Resource Management Act (RMA) are held on the MDC Aquaculture Farm SmartMaps System[5].

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[5] Data presented in these maps can be found on the MDC Aquaculture farm SmartMaps website:
Link: (https://smartmaps.marlborough.govt.nz/smapviewer/?map=6af1f32120314f569f780dafba2647cf)

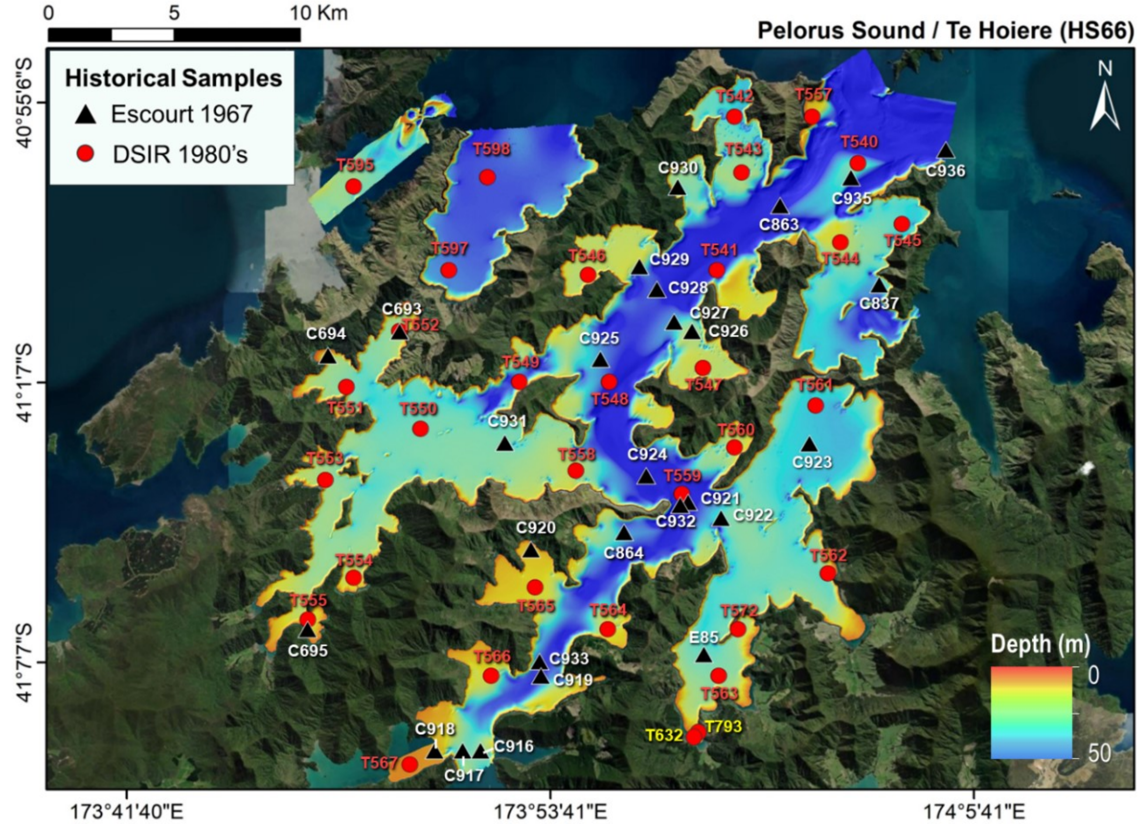

Figure 10. Location of Estcourt (1967) and DSIR 1980's (McKnight et al. 1991a) (historic) biological trawl and grab sites within the HS66 region, overlaid on the HS66 bathymetry. The two yellow labels (Sites T632 and T793) refer to DSIR SCUBA/dive sites collected by C. Hay in 1984 and 1986, respectively.

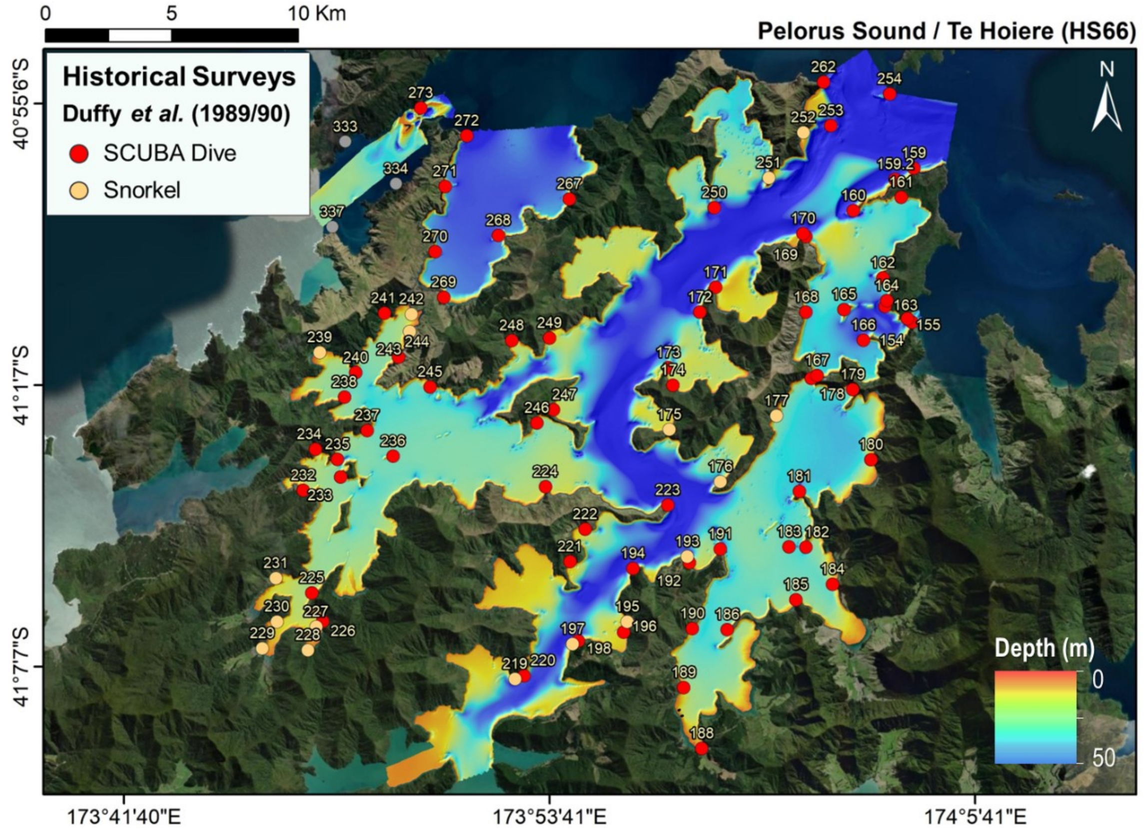

Figure 11. Location of Duffy et al's 1989/90's (historic) dive and snorkel sites within the HS66 region, overlaid on the HS66 bathymetry. Grey circles (not shown in the legend) = sites located outside the HS66 survey area, but within French Pass.

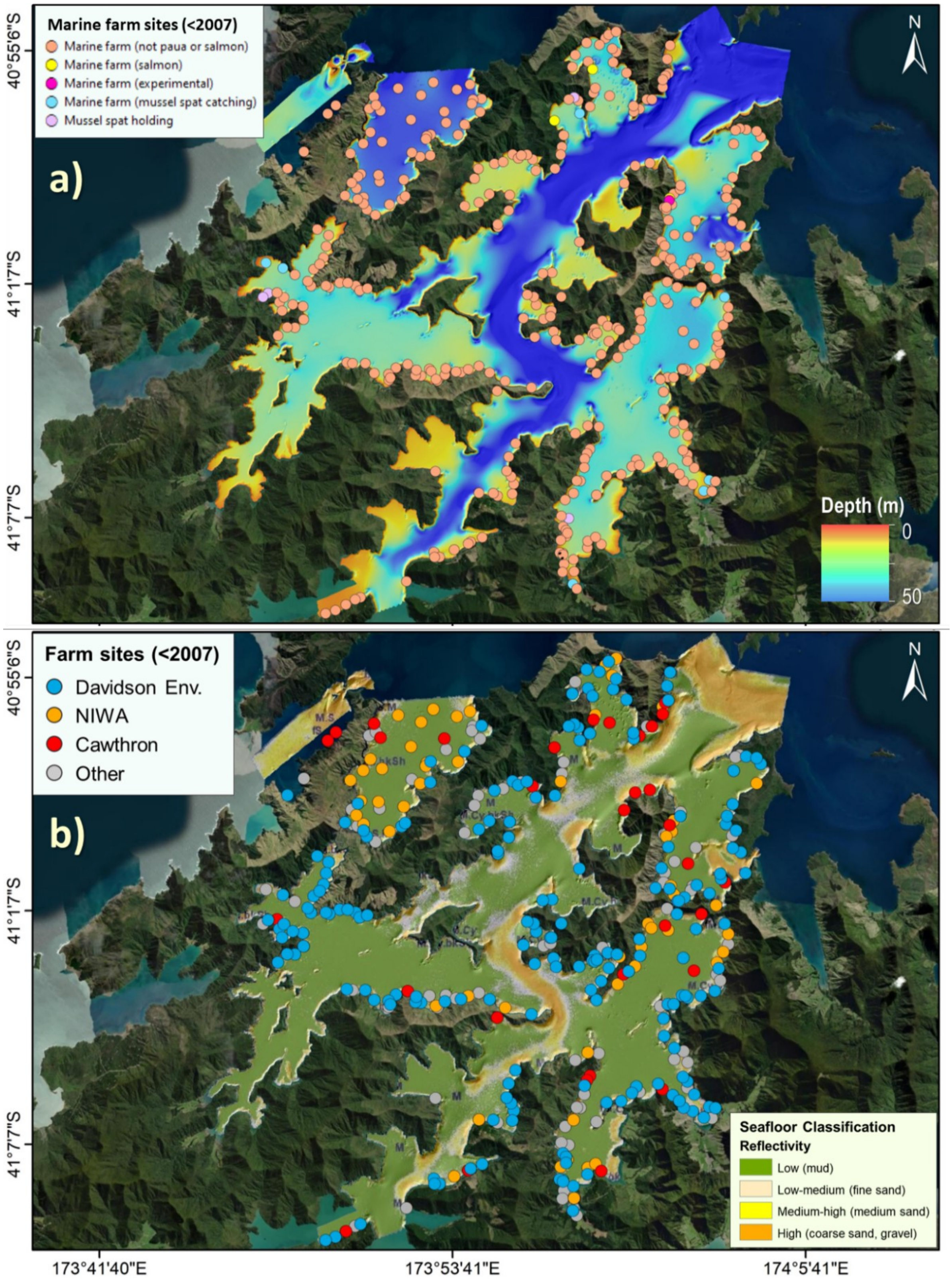

Figure 12. Location of benthic survey undertaken in and adjacent to marine farms (pre-2007), within the HS66 region. a) Sites colour coded by marine farm type (as described in the legend); b) sites colour coded by the Surveyor (specific Institute, agency, consultant), here other refers to all other consultants. This collation of sites is from RMA reports held on the MDC Aquaculture farm SmartMaps system (https://smartmaps.marlborough.govt.nz/smapviewer/?map=6af1f32120314f569f780dafba2647cf), here collated and provided by R. Davidson, Davidson Environmental Ltd.).

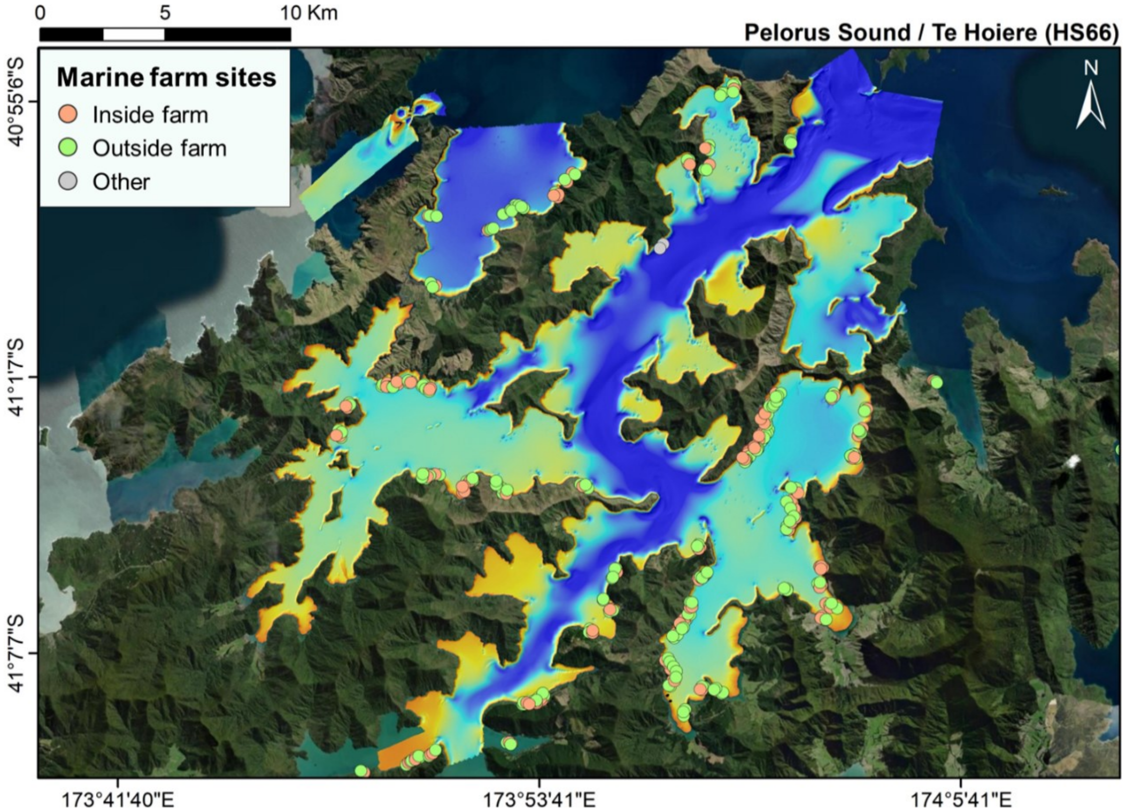

Figure 13. Location of benthic survey sites inside and outside marine farms, within the HS66 region. This collation of sites (as per Figure 12) is from RMA reports held on the MDC Aquaculture Farm SmartMaps System (https://smartmaps.marlborough.govt.nz/smapviewer/?map=6af1f32120314f569f780dafba2647cf), here collated data was provided by S. Handley, NIWA).

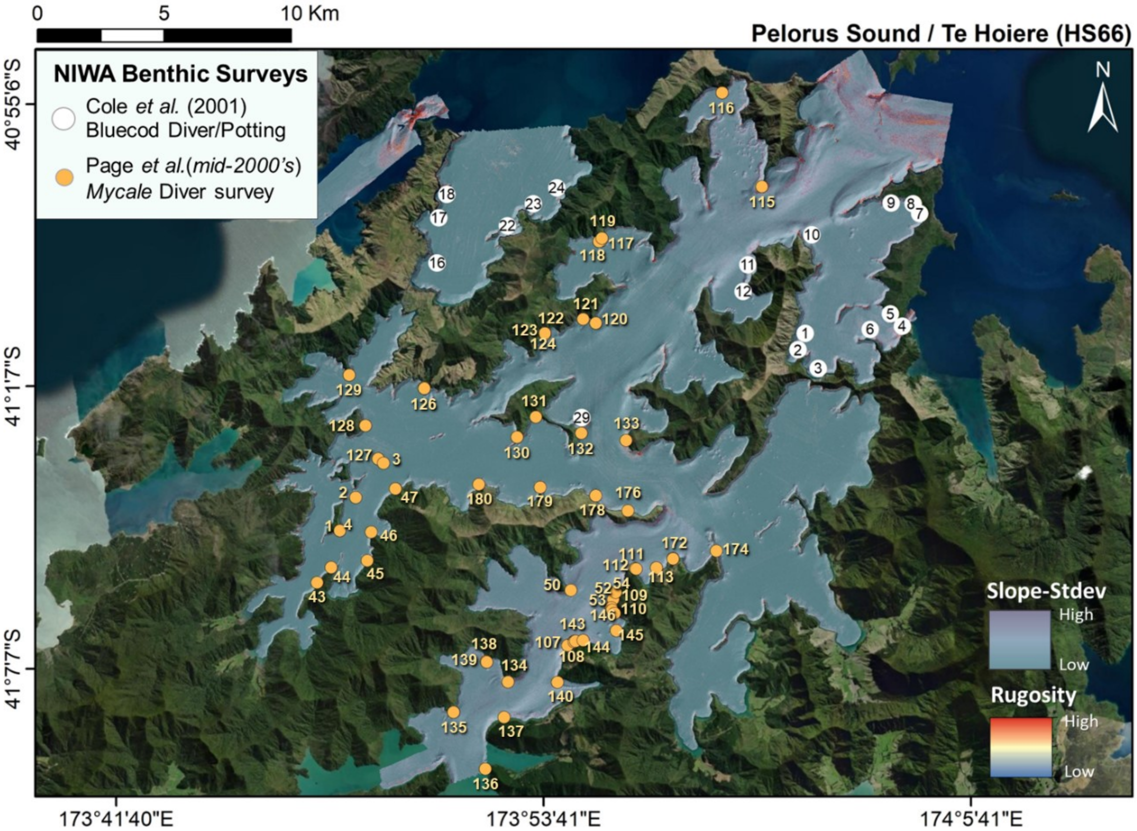

Figure 14. Location of reef-associated benthic surveys for: i) diver and potting surveys of blue cod (Cole et al. 2001) and ii) *Mycale* sponge-discovery surveys (Page and Handley, mid-2000's *unpublished data*). Numbers depict sites numbers for each survey; All sites have been clipped to the HS66 survey area, and are overlaid on the combined seafloor rugosity and slope-stdev, to help depict target reef habitats.

Available farm metadata (data collated and provided by R. Davidson and H. Handley) were imported into ArcGIS, converted into shapefiles, clipped to the HS66 survey area, and then overlaid on the MBES maps to examine all potential relationships. These farm metadata are presented by farm type (Figure 12a), source surveyors (Figure 12b), and as paired 'inside and outside' marine farms sites (Figure 13).

A range of other benthic surveys have also been undertaken, but collation of these surveys was mostly out of scope of this review, unless easily available. However, many of these surveys may also provide very valuable information on the types and past quantities and quality of either nearshore coastal reef or offshore soft-sediment habitats. For example, 102 coastal reef sites were surveyed in the mid-2000's within the HS66 survey area by SCUBA divers looking for the presence/absence of *Mycale hentscheli* sponges (Page et al. 2011; NIWA *unpublished data*; presented as orange-circles and numbers in Figure 14[6]). Likewise, Cole et al. (2001) surveying blue cod undertook both diver and potting surveys at 18 sites within the HS66 survey area (white numbered circles in Figure 14), along with many more sites outside this area. Some of these surveys provide rare insight into the types of biogenic habitats that were present several decades ago. Other surveys that may provide some useful information include stock assessment surveys for blue cod, using either diver and/or potting surveys to examine mostly adult blue cod (>18 cm) stocks and their associated coastal habitats (e.g., Carbines, 1999; Cole et al. 2003; Beentjes and Carbines, 2012). Most of the site locations surveyed are published as maps in their associated reports, along with some related fish counts and/or densities. Several blue cod fishery-stock assessment surveys were also undertaken through time using repeatable potting surveys, with some including GoPro cameras within the pots that provide behaviour footage of the fish, along with some observations or information on the benthic habitats that they sampled (Beentjes and Carbines, 2012b; Beentjes et al. 2017, 2018). A range of blue cod sites were also multibeam mapped

3.2.3.2 Museum & specimen collections

There is currently no single / national database for New Zealand's Museum specimens, rather a wide range of data sources exist that may house specimens (e.g. Museums) or contain specimen records (Ocean Biogeographic Information System [OBIS]) collected from the Marlborough Sounds region, and HS66 survey area (*see Table 2-1* in Anderson et al. 2019). In their review of key biogenic habitats within New Zealand, Anderson et al. (2019) identified a series of key data sources for benthic marine flora (i.e., The Australasian Virtual Herbarium and NIWA's Seaweed database) and invertebrates (i.e., Te Papa Museum, Auckland Museum, NIWA's Vulnerable Marine Ecosystem [VME] data which is also included, along with other specimen data in NIWA's Invertebrate database 'SPECIFY' and OBIS). While these data provide a wealth of distributional data for endemic species, these types of data records have critical biases which are explained in more detail in (Anderson et al. 2019), but in summary, included: i) presence-only data of where specimens were collected (i.e., no absences); ii) a bias towards new, rare and/or difficult to identify species with more common taxa not well represented; iii) Commonly represent a wide range of collection dates, often spanning numerous decades, and as such may no longer represent extant communities.

Many Museum records will also represent specimens collected during previous benthic surveys, incl. those described above, especially the earlier surveys when less was known about the local taxonomy (e.g., Estcourt, 1967; McKnight, 1969; McKnight and Grange, 1991b). However, this may provide a valuable resource with respect to examining benthic community change within the HS66 survey region over historic timeframes (e.g., Handley et al. 2017). Specimen records within the HS66 based on published location records are presented in Figure 15, but these are unlikely to represent the full list of curated specimens. A request to the relevant Museums, Institutes and Agencies (e.g., Te Papa, Auckland Museum and NIWA Specify and OBIS) should be formally made to include a full collation of records for the full Marlborough Sounds region, which can then be clipped to the HS66 region. This

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[6] . Here site locations for Mycale sites were collated and provided by S. Handley, NIWA.

full request is not more effort, and provides MDC with a more valuable overarching specimen-data resource. Although the collation and evaluation of specimen-records is not within the scope of this review, the value of this information is assessed.

Another valuable source of already collated Museum/specimen data, are those present in the review of key biogenic habitat in New Zealand (Anderson et al. 2019), funded by Ministry for the Environment (MfE) for their inclusion in to their Status of the Environment Reporting for 2019. The biogenic data used in the Anderson et al.'s (2019) report was made available to Stephenson et al. 2018 and Lundquist et al. 2020), funded by the Department of Conservation (DOC), for additional collation and the evaluate of Key Ecological Areas datasets for New Zealand marine environment (Lundquist et al. 2020). These biogenic data layers depict key biogenic taxa that have been collated from multiple data sources, including NIWA SPECIFY-Invert, NIWA-Seaweeds, OBIS-NZ, MPI-databases, and museum collections (Te Papa, Auckland Museum) (full description provided in Anderson et al. 2019 and Stephenson et al. 2018). These data come with the same biases and issues described above, but again provide a very valuable resource for determining the types of taxa present. Data includes presence (and abundance where present) of key species of bivalve, sponges (i.e., those species that create 3-dimensional habitats for other taxa), and macroalgal (i.e., those species that create either seagrass meadows or kelp forests, etc.). These data along with updated museum/specimen data layers would be a valuable resource to help assess seafloor habitats and their associated biological communities within the HS66 survey area.

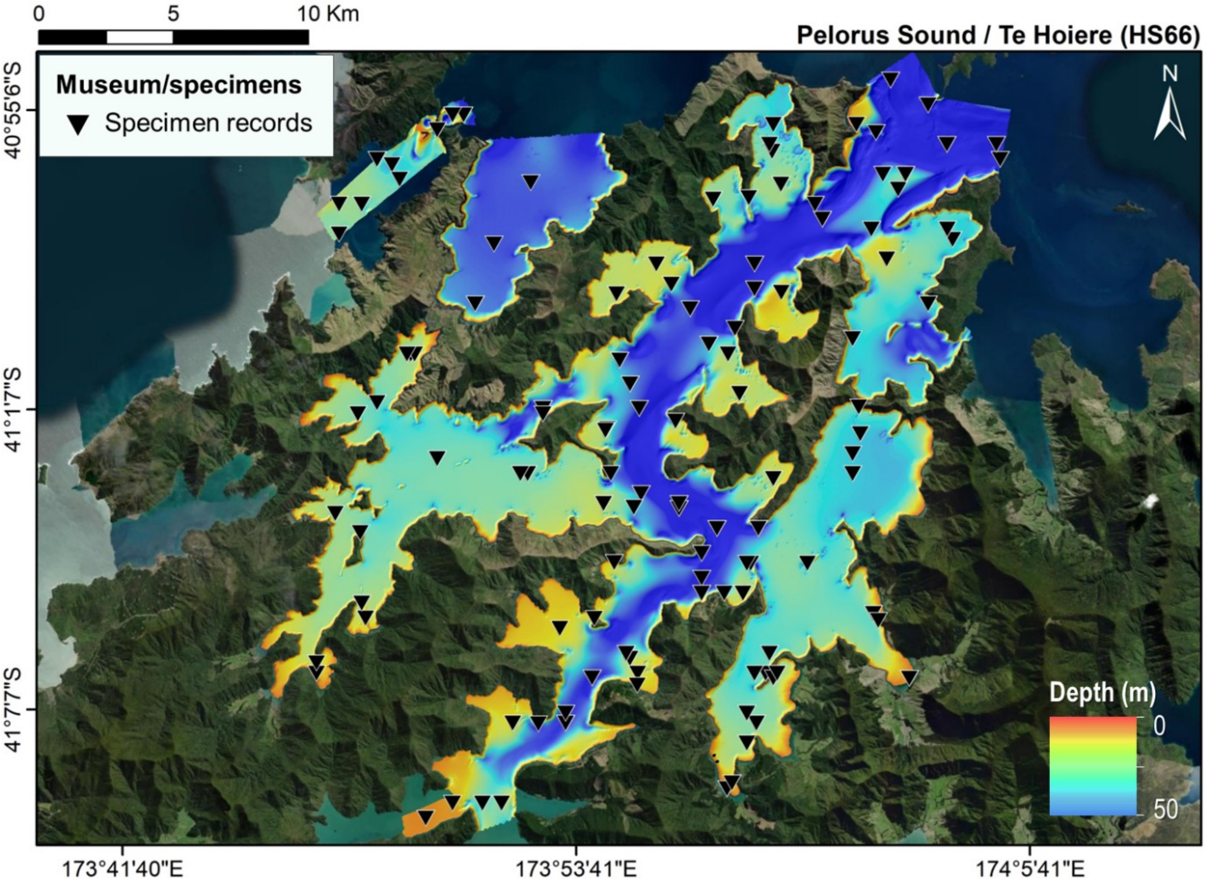

Figure 15. Location of specimen records within the HS66 survey area, overlaid on the HS66 bathymetry. Specimen collection locations are based on available published journal articles and reports, and are not expected to be a comprehensive collation of all specimens from this area.

3.2.3.3 Local Ecological Knowledge (LEK) by long-time fishers

Jones et al. (2016) reported habitat descriptions and spatial locations of historically known biogenic 'living' habitats based on the Local Ecological Knowledge (LEK) of long-time commercial fishers that had worked with bottom-fishing gear (mainly trawlers) and had detailed knowledge of fishing grounds around New Zealand. These spatial polygons and associated descriptions of seafloor habitats were collected from in-person interviews, and included long-time fishers in the Sounds (Jones et al. 2016, 2018; *also reviewed in* Anderson et al. 2019). During each interview, fishers were asked to describe places where they had encountered different or unusual catches of biogenic 'habitat-forming' species. The interview team provided each fisher with visual aids (photographs, and some specimens) and nautical charts, and were asked to draw areas on the charts where they had picked up notable material in the trawl, or they had damaged, snagged, or even lost gear (see Jones et al. 2016 for a full description of the methods). These descriptions of seafloor habitats were then collated and the charts digitised as GIS spatial polygons (Jones et al. 2016), with several key locations around New Zealand later surveyed to evaluate these sites (Jones et al. 2018). It is important to note here, that Jones et al. (2016) emphasize that LEK polygons represent a valuable, but in many places, unverified indication of where biogenic habitats might exist. Specifically, Jones et al. (2016) clarify that some fisher-drawn areas may be at a relatively coarse resolution, and in some instances, may include a proportion of non-biogenic habitat, conversely the biogenic habitat may well extend beyond the polygon, or may no longer be present due to historical changes. However, these historic descriptions provide a valuable source of information about the marine environment, and in combination with other survey data provide a valuable resource to examine the MBES layers. Of the 558 LEK polygons described/and or digitised around New Zealand, 21 polygons represent eight biological habitat types were reported from within the HS66 survey area (*Figure 22 of* Jones et al. 2016). The cropped image of LEK polygons within the HS66 survey areas was then imported into ArcGIS, geo-rectified, and re-digitised using the follow-shape tool (Figure 16). In the current review, these polygons are preliminarily evaluated relative to the HS66 MBES physical layers (e.g., the shape and configuration of the seabed relative to these polygons) and other historic and recent ground truthing information to determine if these habitats still persist; what ground truthing data exist within or adjacent to these areas; and therefore where newly allocated ground truthing sites may contribute both as valuable ground truthing data, but also may provide potentially invaluable information about the condition these key biogenic habitats are in now, and/or how these communities may have changed.

In 2017-19, another LEK interview survey was undertaken as part of the 'Bottlenecks' programme, targeting the Marlborough Sounds region, as one of three regionally targeted areas (the other two being Northland and the Hauraki Gulf regions). However, site-specific habitat and community information are presently unpublished (MBES-funded 'Bottlenecks' programme*, MBIE unpublished data*; Handley et al. *in prep.*).

3.2.4 Fisheries bycatch

Benthic fishery dependent and independent surveys are known to collect a variety of bycatch when targeting specific demersal or benthic species (Tuck et al. 2017). The effects of bottom fishing (especially dredging and benthic trawling) are also known to damage and remove vulnerable benthic habitats and communities, particularly emergent species that stand erect out of the seabed, such as horse mussels, sponges, bryozoans, hydroids, sea pens, tube building polychaetes (Thrush et al. 2016; Tuck et al. 2017; Anderson et al. 2019; Sala et al. 2021). Many of the biogenic ('living') habitats within the Marlborough Sounds, and the diverse communities that they support, are known to be especially vulnerable to benthic fishing activities, such as scallop dredging and bottom trawling (Hay 1990; Anderson et al. 2019; T. J. Anderson, Stewart, et al. 2020). Baird et al. (2015) estimated that approximately 1,000,000 km of coastal habitats (down to 250 m depth) are being impacted by bottom fishing activity each year around New Zealand. NZ scallops, *Pecten novaezelandiae* (here after referred to as *Pecten*), beds have been an important New Zealand Fishery, with scallops common in

Golden and Tasman Bays and the Marlborough Sounds regions – designated as the SCA-7 fishery region - supporting significant commercial and recreational fisheries ((Ministry for Primary Industries, 2017; Tuck et al. 2017). The scallop fishery has operated since the 1950's, and was the largest in New Zealand until its closure in 2016-17, following the decline in scallop biomass (Handley et al. 2017; Fisheries New Zealand, 2022). Scallop dredges often collect a wide range of bycatch (species and benthic biogenic structure) that can provide considerably information on the types of benthic species and communities that are present in an area (*pers. obs.;* Taylor and Morrison, 2008), with their presence providing valuable inference to the type of seafloor habitats present (Taylor and Morrison, 2008). However, they can also denote the removal of some species and material too, and may provide valuable insight into how seafloor habitats may have changed through time. For example, Hay (1990), found experimental scallop dredging had a devastating effect on biogenic communities in the Sounds, documenting stark comparisons between heavily dredged areas characterised by '*featureless bottom'*, and adjacent undredged areas that were characterised by horse mussel communities (3-5 per m^2) fouled with rich epibionts. Although, scallop fishers in many areas tended to avoid dense horse mussel beds as '*mangled shells and epibiota quickly fill up and foul their dredges*', but some fishers also reported the practice of '*flattening these areas to render the bottom more suitable for dredging and trawling*'. Bottom fishing activities have also been reported (by long-time fishers) to target living habitats that support commercially important shellfish and finfish species (Doonan et al. 1994; Cranfield et al. 2001; Morrison et al. 2014; Jones et al. 2016), including within the Marlborough Sounds (Morrison et al. 2014; Jones et al. 2016; Anderson et al. 2019; *also see* Section: 4.4). Yet, globally, many decades to centuries of bottom fishing activities have gone largely unevaluated in terms of their impact on seafloor habitats and/or the communities and biodiversity that they support (Auster et al. 1996; Turner et al. 1999; Thrush et al. 2016; Lefcheck et al. 2019).

Handley et al. (2017) in his review of historical change to the marine environment within the Pelorus Sounds, found a strong spatial relationship between historic (*based on historical beds recorded and drawn by M. Bull;* see Figure 16; Figure 18a) and current scallop fishing activities – based on unpublished Challenger data; but also see Figure 18b, for an indication of scallop fishing effort accumulated in time). Horse mussels (*Atrina*) were also a dominate component of most historical mussel and scallop dredge tows back in the later 1960's (Stead, 1971a, 1971b; (Stead, 1971b; *also see Figure 1-10 in* Handley et al. 2017; Figure 17), where scallop and *Atrina* distributions were known to overlap throughout the Sounds (Hay 1990). Exploratory subtidal dredge surveys for green-lipped mussel (*Perna canaliculus*) were undertaken in the summer of 1968-69, using a commercial mussel/scallop dredge towed for 10 min at each site (Stead, 1971a). In his report, Stead (1971a) reports the location and direction of each of the 13 dredge sites that occur within the HS66 survey area, and indicates whether commercial quantities of any of the three significant biogenic habitat-forming species of subtidal bivalves (*Atrina, Perna* and *Pecten*) were collected (indicated by coloured-ticks in Figure 19). To examine the location of these sites, a .tiff image of map-1 from Stead (1971a) was created and imported into ArcGIS and geo-reference over the base layers. A new shapefile was then created on which polylines were drawn along each trawled line in the map. A data column for the three commercial bivalve species was then included, and a record created for each trawl the three species was collected in. These layers were then plotted in ArcGIS to examine the location of the historic beds and these commercially-viable catches relative to the MBES layers, and the more recent ground truthing and benthic information.

Fisheries bycatch data would be expected to provide a very valuable source of information about what species are/were present, and by their occurrence may provide valuable inference in to what habitats are/were present on the seafloor with the HS66 survey area. For example, bottom trawling for snapper has provide bycatch information on over 70 benthic species (Fisheries New Zealand 2022). For the Marlborough Sounds, there are several relevant fishery research survey datasets that are likely to hold valuable benthic taxa information from either targeted fisheries (e.g. scallops, green-lipped mussels, horse mussels) or collected as associated bycatch (Coral/hard bryozoans, erect sponges, hydroids etc.), with the latter also including the bycatch of commercially-relevant species (e.g., horse mussels, green-lipped mussels and scallops; Anderson et al. 2019). Green-lipped mussel, *Perna canaliculus*, which were once found growing on the seafloor at a range of sites within the inner Pelorus Sounds (Stead, 1971b; *see Figure 1-10 in* Handley et al. 2017), appear to have become ecological extinct - as a once common and locally extensive biogenic habitat. However, early descriptions and maps of their local distributions within the Pelorus Sounds (Stead 1971b, 1971a) provide a valuable resource to examine how the location of these historic beds align with the seafloor features seen in the new MBES-HS66 maps, and more recent ground truthing observations.

Research fishery catch and bycatch data should be requested for the Marlborough Sounds region (*or specifically the HS66 region – as requests may require clear and species intensions for the use of these data*), where requests should include records from:

i) MPI's Centralised Observer Database (**MPI-*COD***).

ii) MPI's research trawl database (**MPI-*Trawl***).

iii) MPI's Oyster bycatch data

iv) MPI's commercial Scallop dredge and bycatch data.

v) MPI's research scallop dredge surveys with fishery effort/catch data for 1994 to 2019

vi) In addition, a request for commercial scallop fishery effort and catch data for 1994 to 2017 can be requested directly through Challenger Scallop Enhancement Co. (Current contact is: Mitch Campbell).

Although many benthic species are collected during benthic fishing activities (Fisheries New Zealand 2022), the taxonomic resolution of bycatch data may differ between data sources. For example, while museum and specimen databases (e.g., Te Papa records) hold curated specimens that are taxonomically identified to species or lowest taxonomic unit (OUT) by international specialists, other data source (e.g., Fisheries NZ databases) are often based only on observer '*in-the-field'* identifications and, as such, are often to a higher taxonomic identification (e.g., phyla, class, family). Although many species level identifications may be included. Most of these data held by Ministry for Primary Industries (MPI), and are regularly updated with revised identifications (Schnabel et al. 2021). However, for the purposes of identifying potentially important habitats and biodiversity within the HS66 region this data may be extremely valuable to identify potential areas that have supported biogenic habitats - such as horse mussels, coral/hard bryozoans, erect sponges, brachiopods – which would all likely be adequately classified for this purpose.

The marine biosecurity porthole (https://marinebiosecurity.org.nz/) may also contain records of non-indigenous and cryptogenic marine species, seen/collected within the HS66 survey area during a range of benthic surveys. MPI are required to be notified of any non-indigenous and cryptogenic marine species if they are seen and/or collects during benthic surveys. Although these are not naturally occurring endemic species, records, would (like the museum species occurrences) provide some valuable inference into the type of seafloor habitat that may be present, and would also identify a potential impact to those natural habitats already present. The national biosecurity surveillance programme is funded by Biosecurity NZ and managed by NIWA (Seaward et al. 2015). Data should be collated from the four main data sources:

i) Port Biological Baseline Surveys (PBBS)

ii) National Marine High Risk Site Surveillance (NMHRSS)

iii) Marine Invasive Taxonomic Service (MITS)

iv) Other verified observations of non-native marine species

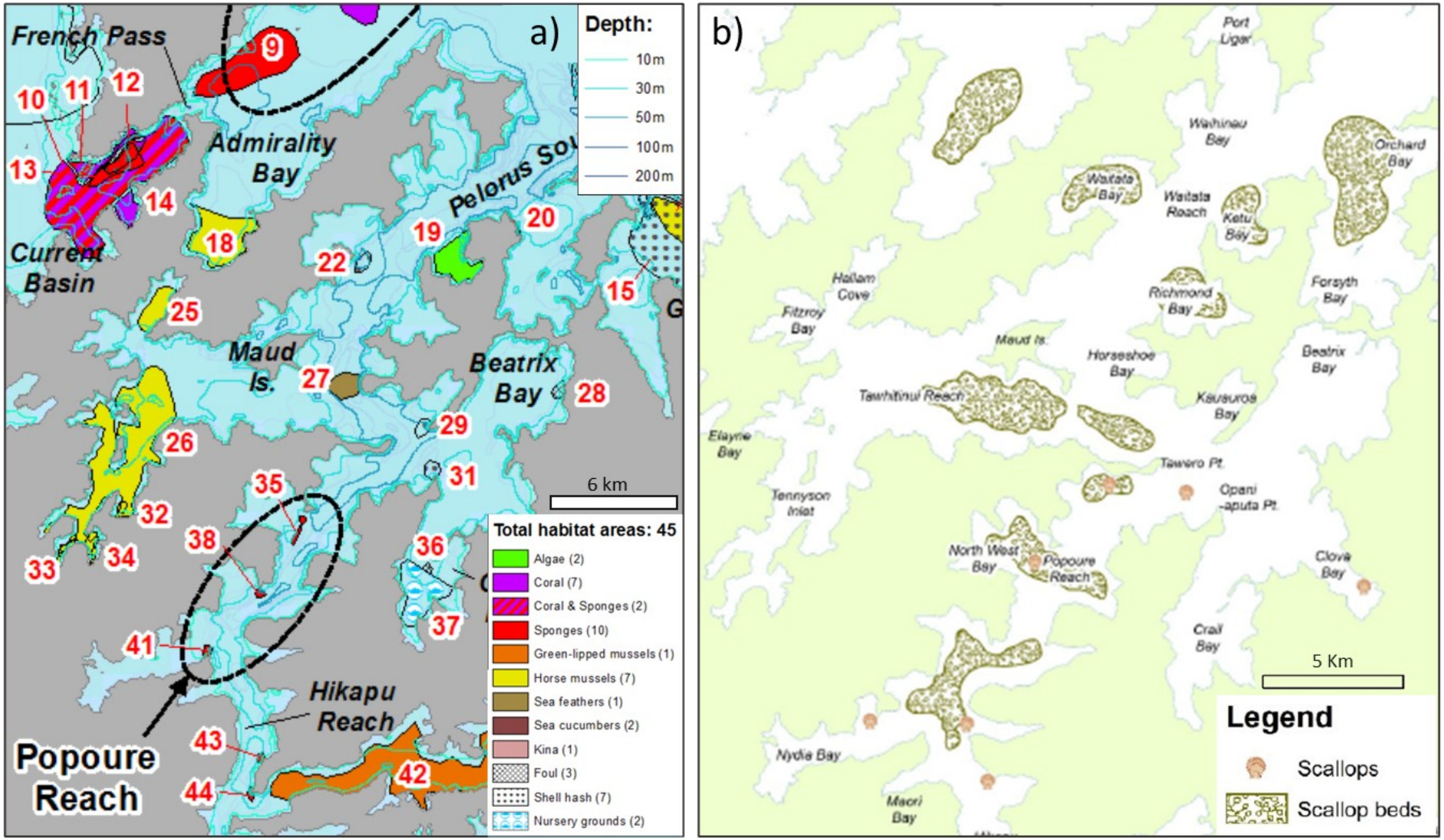

Figure 16. Historical benthic knowledge, within the HS66 region. Local Ecological Knowledge (LEK) polygons within the Marlborough Sounds, including the HS66 survey area (from Figure 22 in Jones et al. (2016). Jones et al. (2016) assigned each LEK area/polygon a unique number, with associated descriptions (*in Table 22 of* Jones et al. 2016); b) Polygons depicting the locations of historic scallop beds (*from Figure 1-11 in* Handley et al. (2017) - originally sourced from Bull [*unpublished map*], presented in Stead, 1971b)

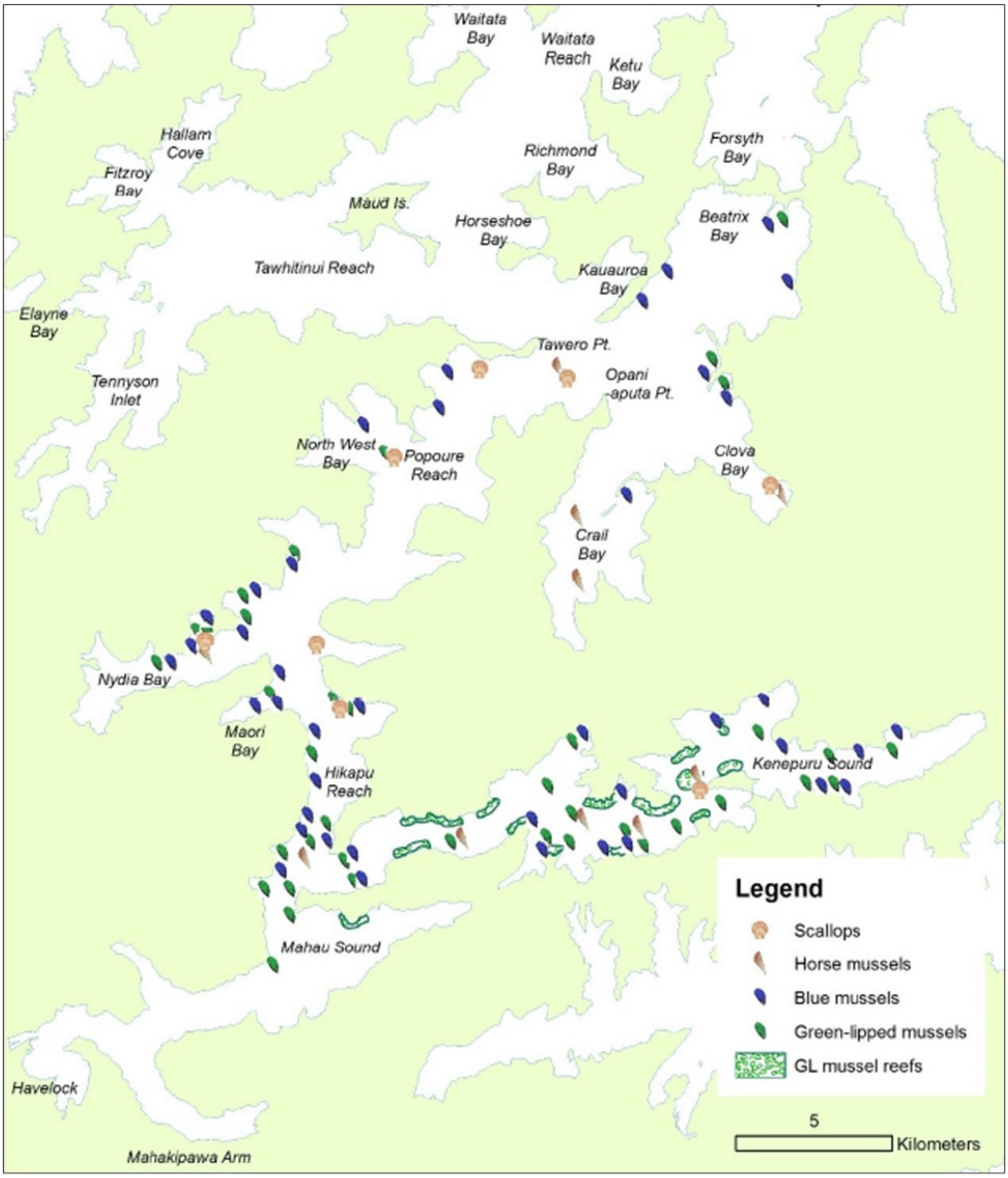

Figure 17. Historical shellfish beds from intertidal and subtidal surveys within Pelorus Sounds (excluding large scallop beds). Cropped image *from Figure 1-11 in* Handley et al. (2017) - originally reproduced from the *unpublished thesis map* of M. Bull in Stead (1971b).

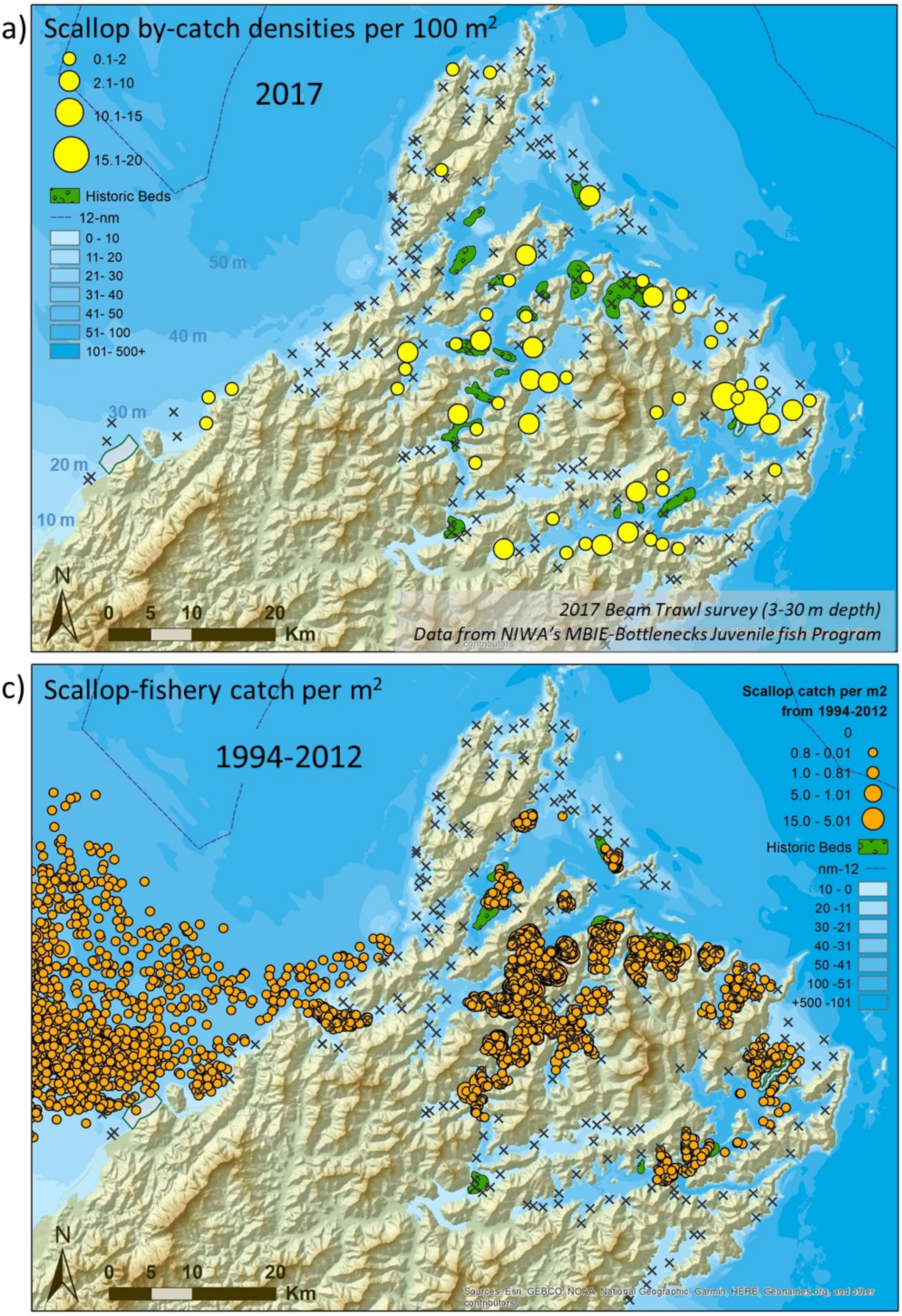

Figure 18. Scallop distribution and abundance in Marlborough Sounds (Image reproduced from *Figure 3-49 in* Anderson et al. 2019).. a) yellow bubble plots = densities of scallop bycatch (counts per 100 m^2) from 3-m wide beam trawl sampling (NIWA Bottlenecks survey 2017), and b) small orange circles = densities of scallops caught in research dredge survey tows in Marlborough Sounds from 1994–2012 (Data source: MPI and CSEC). Green underlying polygons on both maps = depict areas of historical scallop beds (Handley 2017). x indicates sites sampled, but where no scallops were collected.

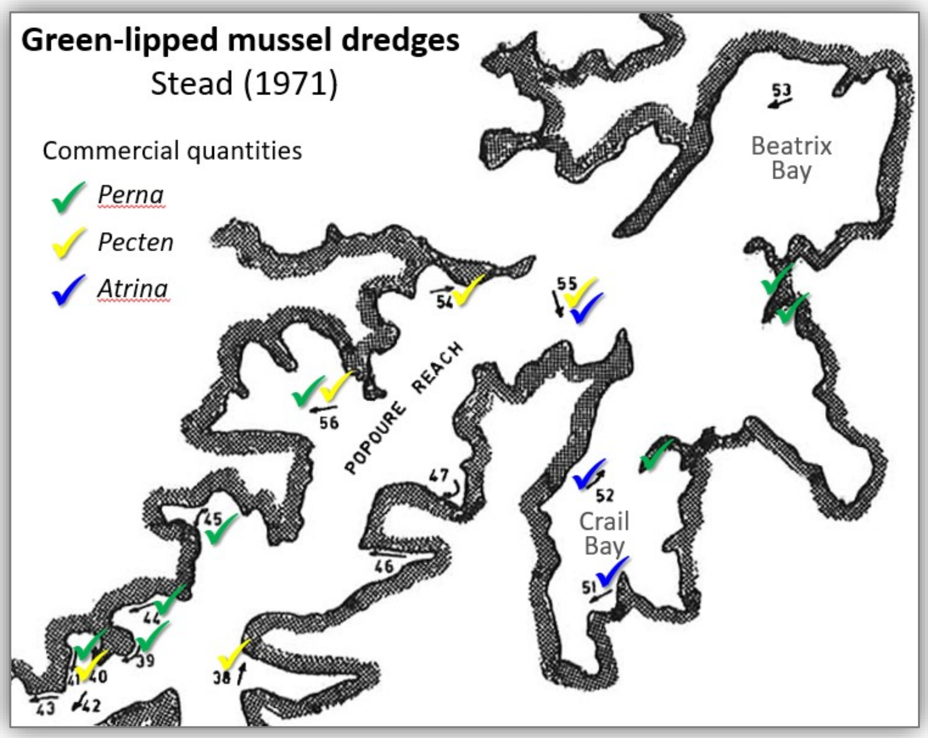

Figure 19. Location of exploratory dredge surveys for green-lipped mussels at sites within the HS66 surveyed in the summer of 1968-69 (cropped area of map-1 from Stead, 1971a). Dredge sites are numbered with the direction of thee dredge indicated by the arrow; coloured-ticks added here visually identify sites where commercial quantities of commercially-important shellfish were collected (i.e., ~>30 indiv.); Green ticks=green-lipped mussels [*Perna canaliculus*); yellow ticks=NZ scallops (*Pecten*); and blue ticks=Horse mussels (*Atrina*).

3.2.5 CBed classification scheme

For many of the existing surveys, descriptions of seafloor substrata and /or biological communities (along with site locations) have been published in reports and journal articles (Estcourt, 1967; McKnight et al. 1991a; Atalah et al. 2011a, 2011b; Jones et al. 2016; Orpin et al. 2020) or are available online on the SmartMap data portal (e.g. farm site surveys). To ground truth and interrogate the MBES layers as tools to target predicted areas of biological diversity, site locations with their descriptions and were reclassified as:

1) **Primary and secondary substrata type** (as per Section 3.2) following the CBED-classification method of) and (Nichol et al. 2009) was used to characterise habitats and community types at each of the new HS66 ground truthing sites (Figure 23; also see Appendix A: Figure 51 and Figure 52). This followed the same methods used to characterise habitats and community types at each of the HS51 ground truthing sites in the Eastern Marlborough Sounds / HS51 survey area (Anderson et al. 2020c), so as to allow between survey area comparisons. This approach was also used to map historical descriptions of habitats and communities, where these characterisations were either based on published descriptions or inferred from biological specimens collected from historical site.
2) A **new 'shell-debris-rank' variable was created** to represent the relative amount of shell debris present at each HS66 ground truthing site. Here, description as of the sediment grab contents and seafloor video descriptions were used to rank the amount of shell debris present at each site using a ranked value of 0-5, where zero=no shell and five=large amounts of shell. This new 'rank' variable, was classified to examine how the amount of shell that was present in the

samples and at each site, might correlate with the amount of seafloor reflectivity measured from the backscatter and used to create NIWA's Seafloor Reflectivity Classification (Figure 24).

3) **The presence of key biogenic fauna and flora** were also described from sites. In most sites this seems to be relatively systematically described. To examine the value of these simple descriptive data[7], presence was recorded for each key taxa type. These are plotted up and evaluated relative to other MBES layers to examine whether they provide insight into potential habitats and community types when visualised spatially (e.g., Figure 25a,b).
4) Marine farm sites metadata that came with analysed **grain size ratios** (i.e., % mud, sand and gravel), were also plotted as shapefiles in ArcGIS and examined as pie-charts and % gravel relative MBES layers, to examine their interrogative value in examining and validating MBES layers, particularly NIWA's SRC layer (Figure 24; also see Appendix A: Figure 53).
5) Newly re-classified sites and variables were plotted as shapefiles in ArcGIS, along with both the geo-referenced images of **local habitat maps** (Atalah et al. 2011a, 2011b; Figure 27 and Figure 28) and **LEK descriptions** (Jones et al. 2016) (see Figure 43 and Table 7); grain size analyses, and any other available shapefiles of **other available data layers**. These new characterisations and maps provide considerable spatial information on the types of substrata that occur across the HS66 survey area, as well as the type types of biological communities they support.

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[7] However, while I examine the spatial relevance of these described taxa, these are only preliminary presence (not true absences), based on very preliminary catch descriptions, so should be scrutinised carefully.

4 *Review of next steps and potential uses*

Biological communities that live on or amongst seafloor habitats are by their necessity related to the structure of the underlying seafloor environment (Ehrlich et al. 1987). Ecological studies have focused on understanding these relationships to enable larger scale inference to be made (McArthur et al. 2010). However, biological surveys are costly and rely on focused fine spatial scale studies. These focused studies aim to understand biological-habitat-environment relationships, which can then be examined and used to better manage and conserve these marine environments. However, extrapolation from these fine-scale studies over large management-relevant scales (10’s to 100’s km) was historically limited to shallow clear water regions where aerial or satellite imagery could be collected (e.g., seagrass meadows and surface kelp). In contrast, our knowledge of what habitats and biodiversity occur in deeper offshore coastal environments and our ability to extrapolate across meaningful management areas (10’s to 100’s km) has been for more limited, with most offshore surveys examining areas tagged for resource mining consents (Nodder et al. 2012; Beaumont et al. 2015). Even within the Marlborough Sounds, large areas of the seafloor were little known beyond diving depths until recent ground truthing campaigns - that extended over the full spatial extent and depth range of the Eastern Sounds -made a wealth of new discoveries of significant biogenic habitats, hotspots in biodiversity, and whole new genera of species that themselves form biogenic zones – never before seen (T. J. Anderson, Stewart, et al. 2020). This identifies the critical need to know what marine environments exist within our coastal environments to enable informed management and conservation plans to be implemented. This is becoming increasingly urgent as coastal habitats and ecosystems are facing accumulating and cumulative human pressures from land and sea (Turner et al. 1999; Thrush et al. 2016; Sala et al. 2021). Coastal marine environments are being exposed to and impacted by increasing land run off (Bainbridge et al. 2018); pollution (Halpern et al. 2008), benthic trawling and dredging (Thrush et al. 2002), over-fishing (Jackson et al. 2001; Pauly et al. 2005; Estes et al. 2011), invasive species (Ehrenfeld 2010) and climate change (Bernhardt et al. 2013; Sala et al. 2021). This combination of coastal impacts can lead to significant loss and unprecedented changes to seafloor habitats, their associated biodiversity and overall ecosystem function (Thrush and Dayton 2002; Sala et al. 2021). As a consequence, it is becoming increasingly exigent to have area-based management that includes knowing what habitat presently exist around our coastlines (i.e., stock-take), what habitats might have already been lost (to know what needs to be restored), and where significant seafloor habitats and associated hotspots in biodiversity occur – so that these significant sites can be protected and conserved. The report reviews how the MBES data can be analysed and used to assist in these spatial marine management and conservation endeavours.

There are several ways that seafloor maps can be used to predictively identify sites that support significant seafloor habitat with diverse benthic communities. These use the same basic principle, which is to use some level of explanatory/predictive relationships between organisms and seafloor habitat maps (verified by direct observation) and then extrapolate these relationships over large management-scale maps – i.e., to predict where you would expect to see similar significant habitats and communities. These areas can then be ground truthed to validate (or fine turn) those predictions. With respects to Marlborough Sounds:

1) This can be achieved **qualitatively**, by visually interrogating all the new MBES-HS66 map layers to look for similar patterns to those already identified in other locations (e.g., Davidson et al. 2010, 2011, 2022; Davidson and Richards, 2016; Anderson et al. 2019, 2020c), particularly organism-habitat-environment relationships already seen/identified across the MBES-HS51 survey area (T. J. Anderson, Stewart, et al. 2020). For this approach to be possible, you need visual maps of the seafloor and some prior knowledge of those important/influential ‘organism-environment’ relationships.
2) This can also be undertaken **quantitatively**, by formally analysing and predictively modelling those ‘organism-habitat-environment’ relationships, and then, using those important/influential

environmental relationships (e.g., with benthic currents, MBES bathymetry, slope, rugosity and seafloor reflectivity, etc.) to extrapolate out over the new unsampled areas: either i) within in the same sample universe, e.g., (Anderson, Anderson et al. 2020; Anderson et al. 2021; Ribó et al. 2021); or, ii) into new areas (e.g., the HS66 survey area) producing a predictive choropleth map (or 'heat' map) showing where other 'suitable-habitat' types exist across these new areas. In step (i) some of the ground truthing data can be used to train the model (i.e., model those 'organism-habitat- environment' relationships), while the remainder can be used to test how well the model predicted those remaining 'known' sites. In step (ii) these predictions need to be validated/assessed by collection new ground truthing data across the spatial extent of the new mapped area (i.e., HS66 survey area). However, for the step (ii) to be quantitatively undertaken, the exact same environmental-map layers used in step (i) to create the habitat-suitability maps, must be available across the new mapped areas.

It is important to clarify here, that these modelled relationships will only be as good as the ground truthing data that has been collected, and where the resolution of the environmental maps (MBES layers) is good enough to resolve biological-relevant patterns in habitat and community distributions. Predicting into new areas is only likely to be successful, where these relationship and scales have been adequately captured and mapped. The resultant maps can then be informally considered as a '***treasure-hunters***' map, whereby predicted 'significant/treasured sites' need to sought out and found (i.e., targeted ground truthing). If the ground truthing from one area is used to predict to a completely separate area, the success will also depend on how similar these environments are.

4.1 Regional setting

The eastern and western regions of the Marlborough Sounds share similar physical and environmental features at multiple scales, making them excellent candidates for predictively modelling approaches. At large scales both regions share similar geomorphologies as extensive 'drowned river valleys', with convoluted fractal coastlines that extend approx. 50 km in length (< 25 km wide) with entrances opening up into Cook Strait (Watson et al. 2020). Both Te Hoiere/ Pelorus Sound and Tōtaranui/ Queen Charlotte Sound are subjected to strong tidally-driven currents that markedly strengthen within the narrow fast-flowing channels (Te Aumiti/ French Pass, Allen Strait, Kura Te Au/ Tory Channel) and towards the north-eastern entrances into Cook Strait (Stevens et al. 2012). There are also share strong gradients in turbidity and sediment deposition (Hadfield et al. 2014; Broekhuizen et al. 2015), with the inner sounds of both regions having weaker currents, elevated turbidity and increased sediment-deposition (Broekhuizen et al. 2015). These two regions also share many similar ecological characteristics, including habitat types (rocky reefs, sediment slopes, extensive depositional mud zones) (e.g., Davidson et al. 2010, 2011, 2022; Davidson and Richards, 2016); taxa and benthic communities, including commercially important scallop beds, horse mussel beds (*Atrina*), brachiopod beds, macroalgal assemblages and infaunal communities (e.g., (Estcourt, 1967; McKnight, 1969; McKnight et al. 1991a; Davidson et al. 2010, 2011, 2016, 2022; Morrisey et al. 2015; Handley, 2016; Handley et al. 2017; Anderson et al. 2019; D'Archino et al. 2019)

Based on these similarities one would expect that predictive species-habitat-environment relationships modelled (theoretically or empirically) in one region would be valuable predictors in the adjacent region. As a consequence of these similarities, information garnered from the Eastern Sounds should be applied to help interrogate and predict significant habitats and communities in the HS66 survey region.

However, there are also some notable differences between these regions. The main one being, two sizeable rivers (The Te Hoiree/ Pelorus and the Kaituna) flow into Te Hoiere/ Pelorus Sound, bring with them freshwater input, while QCS only receives local runoff from small streams (Estcourt 1967; Urlich and Handley 2020). A comparison between modelled near-bottom current strength and the Seafloor

Reflectivity classification maps identify that a key difference between these regions, lies in the current strength down the main channel in Te Hoiere/ Pelorus Sound that forms (or at least correlates 1:1 with) the higher reflectivity zones (characterised as shell-debris zones, as seen in the sections below) - which are not present in the comparative SRC layer for Tōtaranui/ Queen Charlotte Sound (Figure 21). Tōtaranui/ Queen Charlotte Sound, however, does have narrow constrictions in some areas (e.g., Pickersgill and Patten Passage) which may have ecologically relevant comparisons in similar current-strength areas within the HS66 survey area. Both Estcourt (1967) and McKnight and Grange (1991a) described benthic communities from sites in both the Eastern and Western Sounds. Kura Te Au / Tory Channel has consistently stronger currents than the main channel of Pelorus Sound that are characterised by cobbled bottoms (outer Tory Channel) and waved bedforms of coarse shell material (mid-inner Tory Channel) (T. J. Anderson, Stewart, et al. 2020). However, HS66 bathymetry also indicates several locations with waved bedforms that warrant further examination and comparison with Kura Te Au / Tory Channel. Examination of these data relative to differences and similarities, in light of these new MBES layers, along with other available ground truthing data (as seen in the coming sections), would be expected to provide valuable predictive insight (qualitatively and quantitatively) into the types of communities present. It is therefore likely that predictive models built in the Eastern Sounds will have good relevance for the Western Sounds.

Current-swept communities are already known to support hot-spots of marine benthic biodiversity, across the Marlborough Sounds (Davidson et al. 2010, 2011, 2016), with high current flow through constricted channel areas in both the eastern and western sounds, known to support similar communities types (Davidson et al. 2010; Anderson et al. 2020c; Anderson et al. 2019). Near-bottom current speed was also a strong predictor in explaining (and predicting) the spatial distributions of all the key taxa modelled (*Atrina,* Bryozoan patch-reefs and *Galeolaria* mounds) within the Eastern Sounds (Anderson, Anderson et al. 2020; Anderson et al. 2021). This suggests that near-bottom current speed may be an important driver/predictor of species distributions and community structure within the both Tōtaranui/ Queen Charlotte Sound and Te Hoiere/ Pelorus Sound. Marlborough District Council are very fortunate to have hydrodynamic models for both Tōtaranui/ Queen Charlotte Sound and Te Hoiere/ Pelorus Sound. Given that both the eastern and western Marlborough Sounds are very strongly tidally driven, it is very important to be able to examine the variation in current speed across the mapped area. Hadfield et al. (2014) and Broekhuizen et al. (2015a) modelled both the mean surface and near-bottom current speed in both their Tōtaranui/ Queen Charlotte Sound and Te Hoiere/ Pelorus Sound current models. During the 'life of the seabed' programme, examination of both their modelled mean 'surface' and 'near-bottom' current speed relative to observed biological patterns across the HS51 survey area identified that, unsurprisingly, near-bottom current speeds were found to be more closely correlated with biological communities patterns (T. J. Anderson, Stewart, et al. 2020), than surface currents. As part of this review, 'near-bottom current speed' for the western Sounds was draped over the hillshade relief for MBES-HS66 (Figure 20). Although the Te Hoiere/ Pelorus Sound current model was created in 2014-15, using much older ROMS bathymetry, there was still an excellent alignment between the modelled mean near-bottom current speed and both a) the newly mapped HS66 seafloor bathymetry (Figure 20) and, b) NIWA's SRC layer based on the unprocessed backscatter mosaic (Figure 21). Here, the highest current areas occur down the main artery (main channel) of the Te Hoiere/ Pelorus Sound and through Allen Strait (*i.e., the darker red sections along the channel in* Figure 20). These high current areas also align near perfectly with the sections of high reflective seafloor (cream-orange zones) in NIWA's SRC layer (Figure 21). Existing ground truthing (Figure 22; also see sections below) found these areas of high reflectivity to be comprised of varying amounts of either: accumulated 'whole' shell debris armouring the seafloor (particularly in the entrance to Te Hoiere/ Pelorus Sound (Figure 22a,d); shell-debris with biogenic structure (Figure 22b,c); or shell-debris mixed into the sediment matrix (Figure 22e,f). Shell-debris buried but lying near the sediment surface may also cause higher backscatter signals that are mud without shell, identifying the importance of modelling and validating this variation in shell-debris habitat types. Distinct high reflectivity shell debris zones were recorded along sections of the main channel, and were strongly spatially correlated (1:1 alignment) indicating that strong channel currents may accumulate shell debris in deeper sections of the main channel and preclude these shells being buried by depositional sediments.

The strong correlation between these layers and observed benthic habitats indicates there is real value in modelling these relationships. The strong correlation between the near-bottom current speeds and NIWA's SRC layer also identifies that one layer could be used as a proxy for the other (i.e., near-bottom current speed, as a proxy for the SRC). However, examination at finer zoomed-in levels found that NIWA's SRC layer provides more accurate alignment with the bathymetry than the modelled currents – as would be expected, given that the benthic currents were built on older and lower resolution bathymetry. Regardless, the near-bottom currents layer is an excellent fit given its older age, and also provides added value to examine current-swept communities across this region, particularly where rock outcrops protrude out into the high currents of the main Te Hoiere/ Pelorus Sound channel (see rocky outcrop section below), and, as such, would be expected to be an important predictor of many community types occurring within the HS66 area.

The Te Hoiere/ Pelorus Sound model of 'near-bottom current speeds' includes Admiralty Bay, but does not include the area around Te Aumiti/French Pass (Figure 20; Broekhuizen et al. 2015b). It would, however, be valuable to examine the determine if existing ROMs data can be used to extend the Pelorus model to include Te Aumiti/French Pass. Previous work has been undertaken to measure tidal flows through French Pass (Stevens et al. 2008), with Stevens et al. (2008) reporting spring tidal currents exceeding 4 m s^{-1} through the 'throat' of French Pass (up to 8 knots Baldwin 1979), indicating that observed measurements over this area are available.

4.2 Ground truthing data – Assessment of MBES layers

There is considerable information and knowledge, already available, from a range of recent and historical benthic surveys, along with other types of LEK and historical sources to help interrogate and evaluate MBES layers

These including:

1) The recent HS66-2020 ground truthing campaign (largely reflecting NIWA's HS66-2020 video and sediment grab sampling; along with sediment grabs from some additional sites collected by iXblue and DML; *see* Orpin et al. 2020) (Figure 23 shows seafloor characterisations for all surveys combined; but see Appendix A-Figure 51 for HS66-only site characterisations).
2) Historic benthic surveys collecting grabs and dredge samples (i.e., Estcourt, 1967 and McKnight and Grange, 1991a, respectively) (Figure 23 all surveys combined; but see Appendix A-Figure 52 for historic-only survey sites).
3) Nearshore grain-size information (% mud, sand and gravel analyses) from inside and outside farm sites throughout the HS66 surveyed area (e.g., *grey bubble sizes in* Figure 24; but see Appendix A-Figure 53[8] for full pie-chart presentations of sediment composition at each site). These data include recent and historic surveys.
4) Recent small-scale local habitat maps, created by Cawthron and reported in published habitat maps for several potential and occupied marine farms sites (e.g., Figure 27 and Figure 28).
5) Historic Local ecological knowledge (LEK) polygons of historically-known biogenic habitat zones (Figure 43) as well as past research showing sites and maps verifying the location of historic biogenic habitats (e.g., Stead, 1971b).

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[8] Collated over the years by Dr S. Handley, and provided for use in this review.

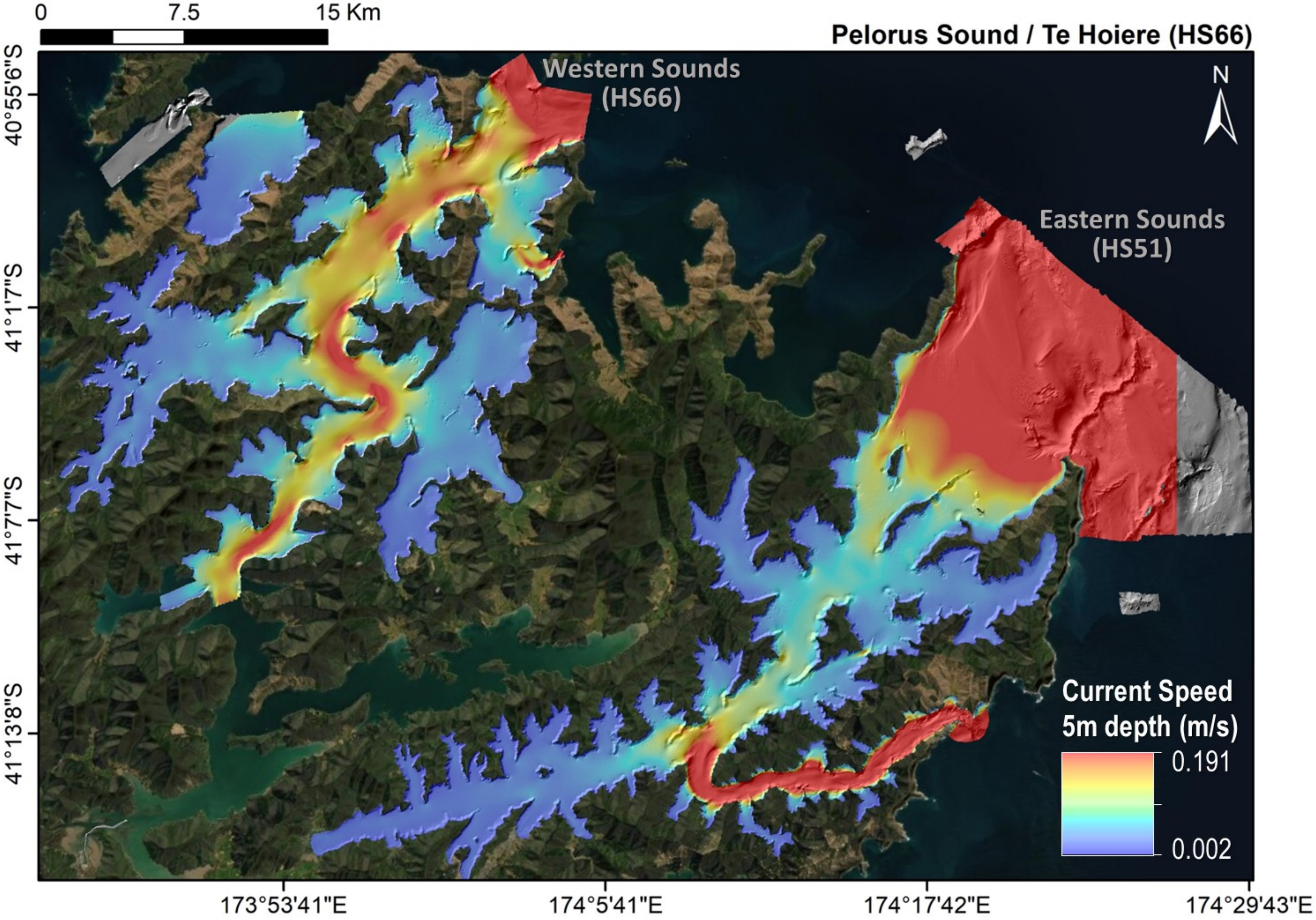

Figure 20. Spatial comparisons of modelled mean 'near-bottom' current speeds (at 5 m depth) for the Eastern (HS51) and Western (HS66) Marlborough Sounds, overlaid on the HS66 hillshade relief. Models are from Hadfield et al. 2014 (HS51); Broekhuizen et al. 2015b (HS66). The HS66 model does not include French Pass.

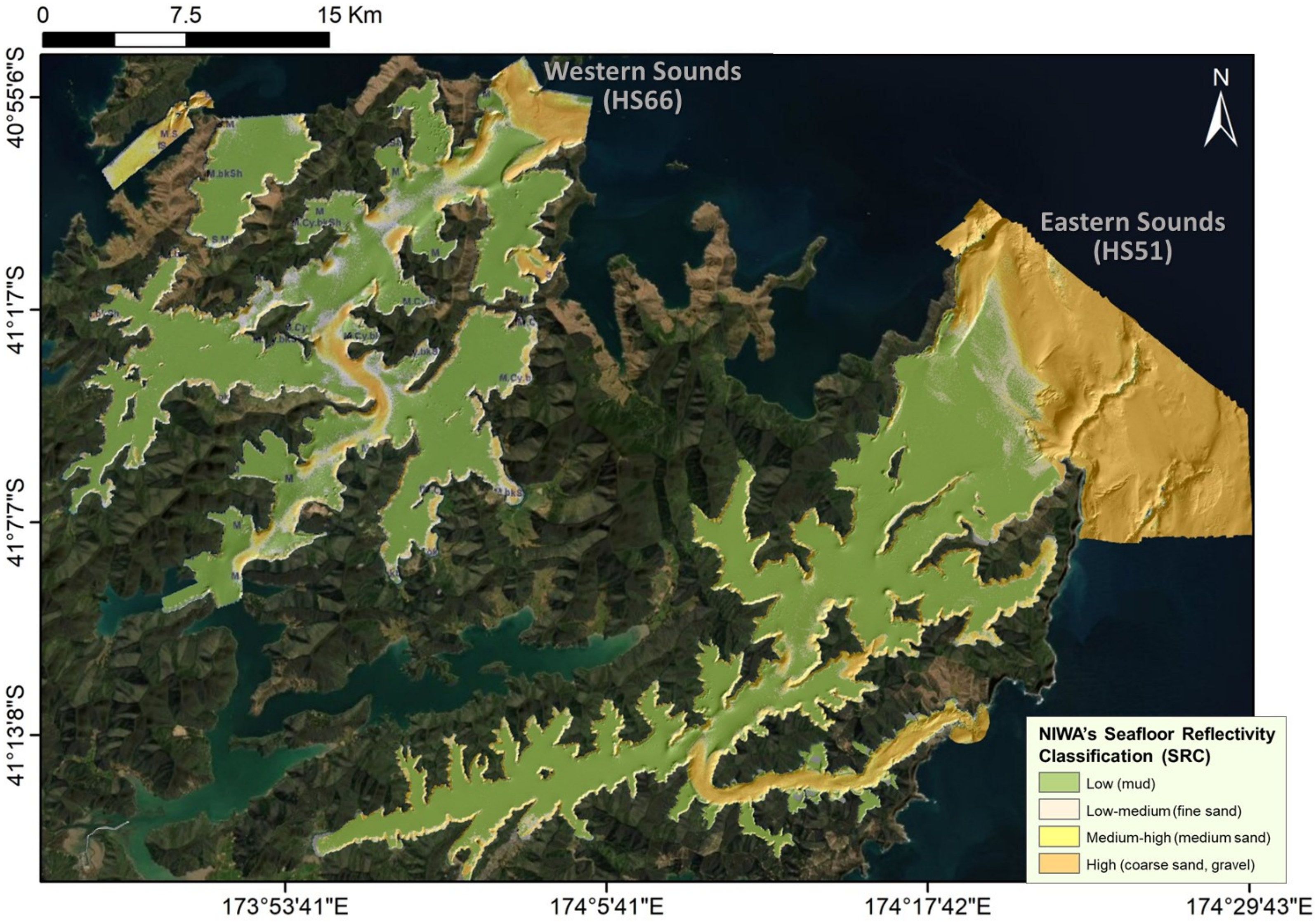

Figure 21. Spatial comparisons between NIWA's Seafloor Reflectivity Classification (RC) layers for the Eastern (HS51) and Western (HS66) Marlborough Sounds, overlaid on the HS66 hillshade relief. A geo-rectified image of NIWA's preliminary SRC is presented for the HS66 survey (drawn from unprocessed and uncalibrated backscatter data; details provided in Orpin et al. 2020), while the HS51 survey is represented by a fully processed and well validated SRC raster (Neil et al. 2018).

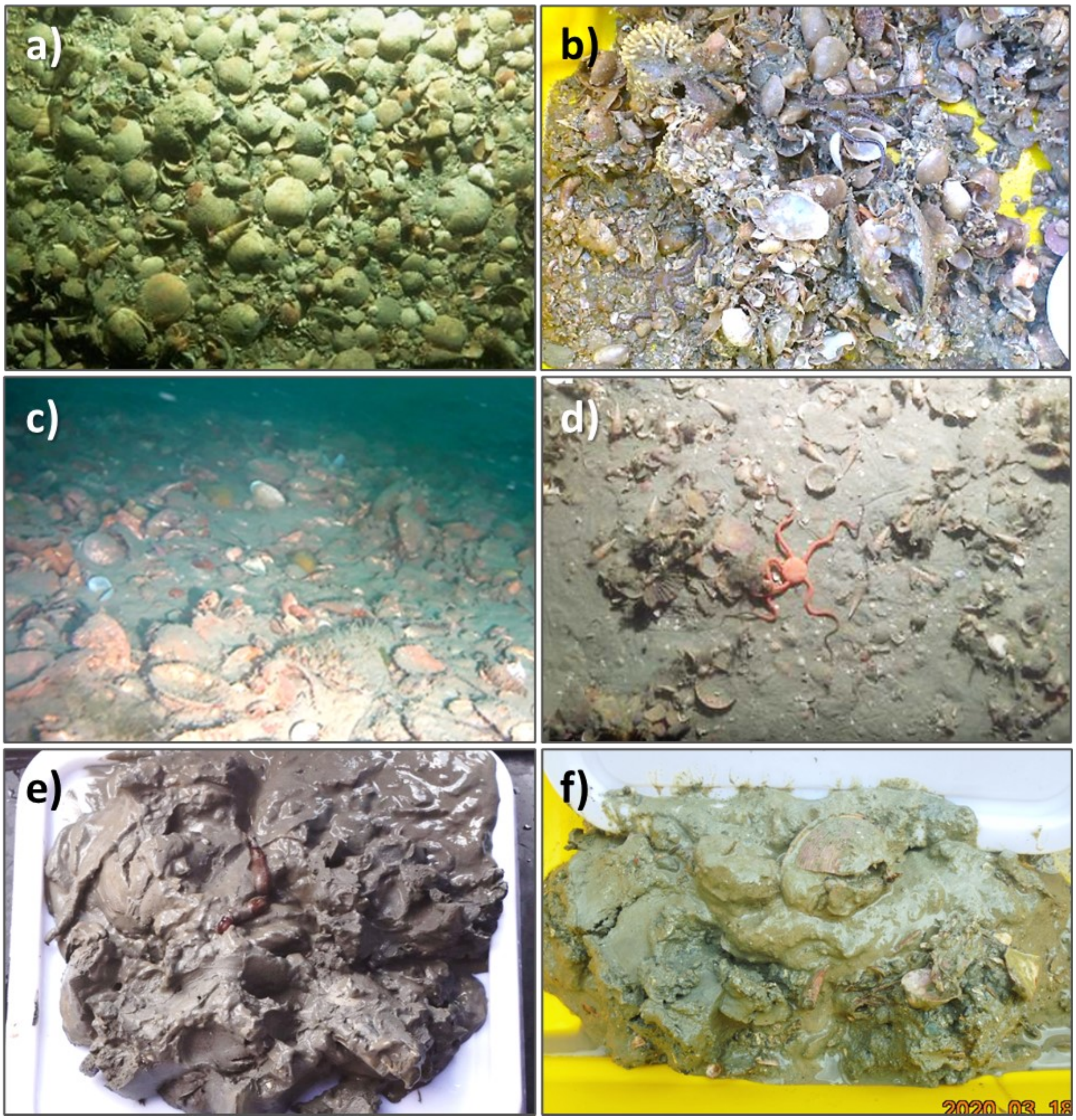

Figure 22. Examples of different types of shell-debris habitats recorded within the Western Sounds (HS66 survey area). a) Shell-debris (armoured) habitat in the outer entrance to Pelorus Sounds (HS66-2020, Site PS-ENT22, 95 m); b) Shell-debris with bryozoan corals from Allen Strait (HS66-2020, Site AS-1, 41 m); c) extensive shell-debris slope southern end of Blowhole South, Pelorus North; d) Patchy shell debris in eastern channel of Pelorus Sound (HS66-2020, Site PS-ENT27, 56 m); e) Mud with broken shell, Wilson Bay, Pelorus South collected by DML (HS66-2020, Site G49, 14 m); f) Shell and mud matrix, Savill Bay, collected by iXblue (HS66-2020, Site SS05, 14 m). Images a,b and d are from Orpin et al. (2020), Image-c is *from Figure 3-12 in* Brown et al. (2016).

4.2.1 New CBed habitat & taxa classifications

For many of the existing surveys, valuable localised habitat maps and / or descriptions of seafloor substrata and /or biological communities (along with site locations) have been published in reports and journal articles (Estcourt, 1967; McKnight et al. 1991a; Atalah et al. 2011a, 2011b; Jones et al. 2016; Orpin et al. 2020) or are available online on the SmartMap data portal (e.g. farm site surveys). To examine how accurately NIWA's SRC layers and benthic attribute layers correlated with ground truthing data (i.e., observed seafloor substrata, shell content and community types), the new CBed classifications for recent and historical data were plotted sequentially over the new HS66 seafloor layers. The new CBed-classifications, included:

1) **CBed primary and secondary substrata type** can be plotted over various MBES and environmental layers to examine the spatial distribution of observed substrata types relative to patterns seen in the physical layers, and other ground truth these layers (e.g., Figure 23 for all surveys combined; but see Appendix A-Figure 52 for sites separated by recent (Appendix A-Figure 51) versus historic (Appendix A-Figure 52) surveys).
2) The **new 'shell-debris-rank' variable** (0-5 rank, where zero=no shell and five=large amounts of shell). This new CBed 'shell-debris-rank' variable will be particularly important in assessing NIWA's Seafloor Reflectivity Classification layer (e.g., Figure 24), but also in determining where shell-debris zones are that may support biogenic communities, including those characterised by sponges and bryozoans (either in the past or presently).
3) **The presence of key taxa** - indicative of potential habitat types. Here, the spatial distribution of key fauna and flora as well as lebensspuren (signs of life, such as track and trails) can be examined relative to MBES layers. The simple plots of described presence of indicative taxa can, when examine spatially, provide considerable insight into the types of seafloor habitats and communities that may be present (e.g., Figure 25a,b).
4) Marine farm surveys that include analysed **grain size ratios** (i.e., % mud, sand and gravel) provide valuable information to validate MBES layers – albeit most of these are nearshore farm sites. However, the % gravel when plotted along with CBed shell-debris (Rank %cover) can provide extremely valuable information for assessing the MBES layers, particularly the in assessing the reliability of the reflectivity classes in NIWA's SRC layer (see *grey bubble sizes in* Figure 24). However, independently, the full pie-chart presentations of sediment composition also provide detailed grain size composition relative to all the MBES layers (e.g., Appendix A-Figure 53[9]).

The new CBED-classification layers provide a wealth of spatial explicit[10] information to examine and interrogate the new MBES and environmental (near-bottom current) layers, and as such these data already provides some excellent insight for qualitatively (visual) interpretations, and can now be interrogated at finer-scales to evaluate predicted, past and potential sites of biological significance. In this review the new CBed primary and secondary substratum classifications have been plotted across the MBIE-HS66 bathymetry (Figure 23; Appendix-Figure 51a) and NIWA's SRC layer (Figure 24; Appendix-Figure 51b), to evaluate and review the potential uses of these layers. These initial example evaluations have already identified that:

1) There is already quite a wealth of existing ground truthing information with which to interrogate the HS66 multibeam (MBES-HS66) maps;
2) The combination of this information (as part of this review) has already been fruitful in predicting new habitats (with some examples shown below), and as such,
3) Can already be used to predict 'new' biologically significant areas (using qualitative visual interrogation of the combined ground truthing and MBES-HS66 maps); and
4) Difference between the HS66 and HS51 environments can now be used to examine what other variables maybe important in predicting 'new' sites of biological significance within the Western Sounds.

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[9] Collated over the years by Dr S. Handley, and kindly provide for use in this review.

[10] albeit only one GPS recorded position per surveyed HS66-site, even where transects were run over the seafloor for an extended area/duration of up to ~10 minutes, and observed multiple types of habitats. Consequently, the location of all these habitats (within the site), except for the ones at the starting position, is unknown.

Table 4. Ground truthing data sources available within the HS66 survey area, as published or provided, where CBed habitat and biological characterisations could be created (n=331 sites) or where some habitat data* was available (n=534 sites).

No. of sites	Source	Habitat	Biology
218	Orpin et al. (2020)	✓	✓
55	R. Davidson (Provided for the purposes of this review)	✓	✓
31	McKnight and Grange (1991a)	✓	✓
27	Estcourt (1967)	✓ *Inferred from biology*	✓
203*	MDC-Farm sites data (SmartMaps) (Collated by S. Handley)	**Grainsize** ✓	-[1]
331	Total CBed characterisation	✓	✓
534	Total sites with some habitat data	✓	

[1] Some biological data available/provided but not examined here.

4.2.2 *Review of preliminary CBed-MBES relationships*

Mapping the new CBED classifications for the available ground truthing data, from both the recent MBES-HS66 ground truthing campaign (as described well in Orpin et al. 2020), and the historic benthic surveys (i.e., Estcourt, 1967; McKnight and Grange, 1991a) provided some valuable initial information on the types of seafloor habitats present within the HS66 survey area. For example, MBES layers, particularly NIWA's SRC layer identified that the central channel within the Te Hoiere/ Pelorus Sound is characterised by areas of high reflectivity, particularly at the entrance to Te Hoiere/ Pelorus Sound and through the S-bend channel in the mid-channel/Waitata Reach region (Figure 21). Here, primary and secondary substratum type identify that these high reflectivity areas are comprised of varying amounts of whole and or broken shell debris (e.g., Figure 22, Figure 23 and Figure 24). Here, these high reflective zones were characterised by muddy sediments with varying levels of shell debris either intermixed within the sediment or accumulated as shelf debris armouring the seafloor (e.g., Figure 22). Similar patterns were also seen in the CBed classifications of the historical data (Appendix-Figure 52a,b; as well as Figure 23), indicating that these historical habitat descriptions can also be very valuable in evaluating MBES layers (and possibly predicting and delineating seafloor habitats) - although careful consideration of how habitats may have changed is required here. These historical characterisations along with the recent ground truthing data, identify coarser shell debris areas that align and validate the high reflectivity zones in NIWA's SRC layer.

Spatial evaluation of the amount shell debris descriptions (HS66-2020 ground truthing data, presented here as rank %cover) along with % gravel from past farm surveys (based on grain-size analyses) also proved to be extremely useful in assessing the amount of shell present relative to the backscatter reflectivity depicted in NIWA's SRC layer (Figure 24 and Appendix A-Figure 53, respectively). Here, higher shell debris was strongly correlated with higher reflectivity (Figure 24). The higher reflectivity shell debris habitats were found in deeper channels (e.g., entrance to Pelorus Sounds / Te Hoiere) and in locally deep holes around headlands (e.g., Kaitira, East Entry Point). These plots however also identify a notable lack of ground truthing sites in low reflectivity zones, particularly around Tawhitinui Reach to the west of the main channel and similarly to the east of the main channel NE of Ōpani-āputa Point towards Beatrix Bay. This would likely cause some issues in terms of generality of extrapolating the inverse (i.e., low shell debris) over these mud areas, given how few mud sites there are in the HS66 survey. Orpin et al. (2020) clearly describe their sampling design and allocation reasoning (i.e., to ensure good coverage over the more complex higher reflectivity habitats), predictive modelling relies on modelling relationships, and in doing so requires sampling across the full range of conditions. The full range of habitat types should be adequately sampled to ensure reliable extrapolations can be made across the maps. More ground truthing sites should be included with in a range of low reflectivity areas, including around Tawhitinui Reach and NE of Ōpani-āputa Point if adequate samples cannot be achieved through the collation of already existing ground truthing data.

To examine if the different seafloor reflectivity classes supported different and spatially consistent taxa, two contrasting community types were plotted: Taxa and classification types representative of soft-sediment communities (Figure 25a) versus those representative of biogenic communities (Figure 25b). These are all based on simple presence information based on the descriptions of fauna and flora reported in Orpin et al. (2020). Although these layers represent only a very simple presence-only descriptor, when overlaid on the various MBES maps, particularly NIWA's SRC layer, they already provide an insightful landscape-view of habitat-organism distributions (e.g., Figure 25a and Figure 25b). Here, the distributions of the two contrasting community types plotted in Figure 25a and Figure 25b indicate that shell-debris accumulation in the deeper bathymetric sections of the Te Hoiere/ Pelorus Sound channel, notably through Waitata Reach and Popoure Reach, appear to provide an important shell-debris substrate for sessile invertebrates, such as sponges, bryozoa, hydroids and epiphytic bivalves (notably *Talochlamys*). Video imagery should be more quantitatively examined. These patterns, however, are also supported by benthic surveys undertaken by Brown et al. (2016), who surveyed sites around potential new farm areas including sites with the centre of the Waitata Reach Channel. In these surveys, Brown et al. (2016) reported muddy sediments with little shell-debris in areas classified as low reflectivity muds in NIWA's SRC layer, as well as patches of shell debris with attached *Talochlamys* that aligned with higher reflectivity in NIWA's SRC layer. Many of these shell debris zones border either dog cockle sites (e.g., outer Pelorus Sounds) or scallop beds (e.g., Figure 25), where shell-debris of both species were commonly reported (e.g., Orpin et al. 2020). Here, the provision of fisheries bycatch data across the HS66 survey areas, would provide an excellent resource to help determine what types of bycatch/species (and colonisation stage) have been collected in these muddy versus shell-debris zones. These shell debris habitats are likely to be an important substrata for a diverse range of sessile epifauna and flora, particularly where shell debris is stable and becomes bound together by biota, such as hard frame-building bryozoans, encrusting sponges and colonial ascidians (Davidson et al. 2010, 2011; T. J. Anderson, Stewart, et al. 2020). However, high reflectivity areas may not always represent hard available substrata, but rather high amounts of shell debris within the matrix of the mud. Here evaluation of the video footage is critical to quantify and evaluate this pattern.

The ability to interrogate these sequential map layers, run depth profiles across these areas, and examine the available ground truthing provides an incredible wealth of information to predict/identify (depending on the ground truthing available) the habitats types and communities present. Where these interrogations identify important habitat inferences, and there are not ground truthing data, then this identifies the need to collect information from these new sites. While one-off stepped or targeted collections are valuable (especially where they can piggy-back on other projects), it is important to ensure that 'new' ground truthing data enable an assessment of how representative various habitats are. It is also important not to assume that some habitats are more diverse than others. There is often a tendency to focus on epifaunal communities and assess diversity based on the above ground structure and community. The Marlborough Sounds comprises a wide range of benthic marine habitats, that include hard and soft-sediment communities. With invasive species on the rise, and environmental changes predicted, it would be prudent to known what types of benthic communities exist presently within the sounds. Adequate spatial allocation of /ground truthing sites, should enable a regression approach to be used to model the relationships between the physical and environmental setting of the sounds and the spatial configuration of the communities that occur there.

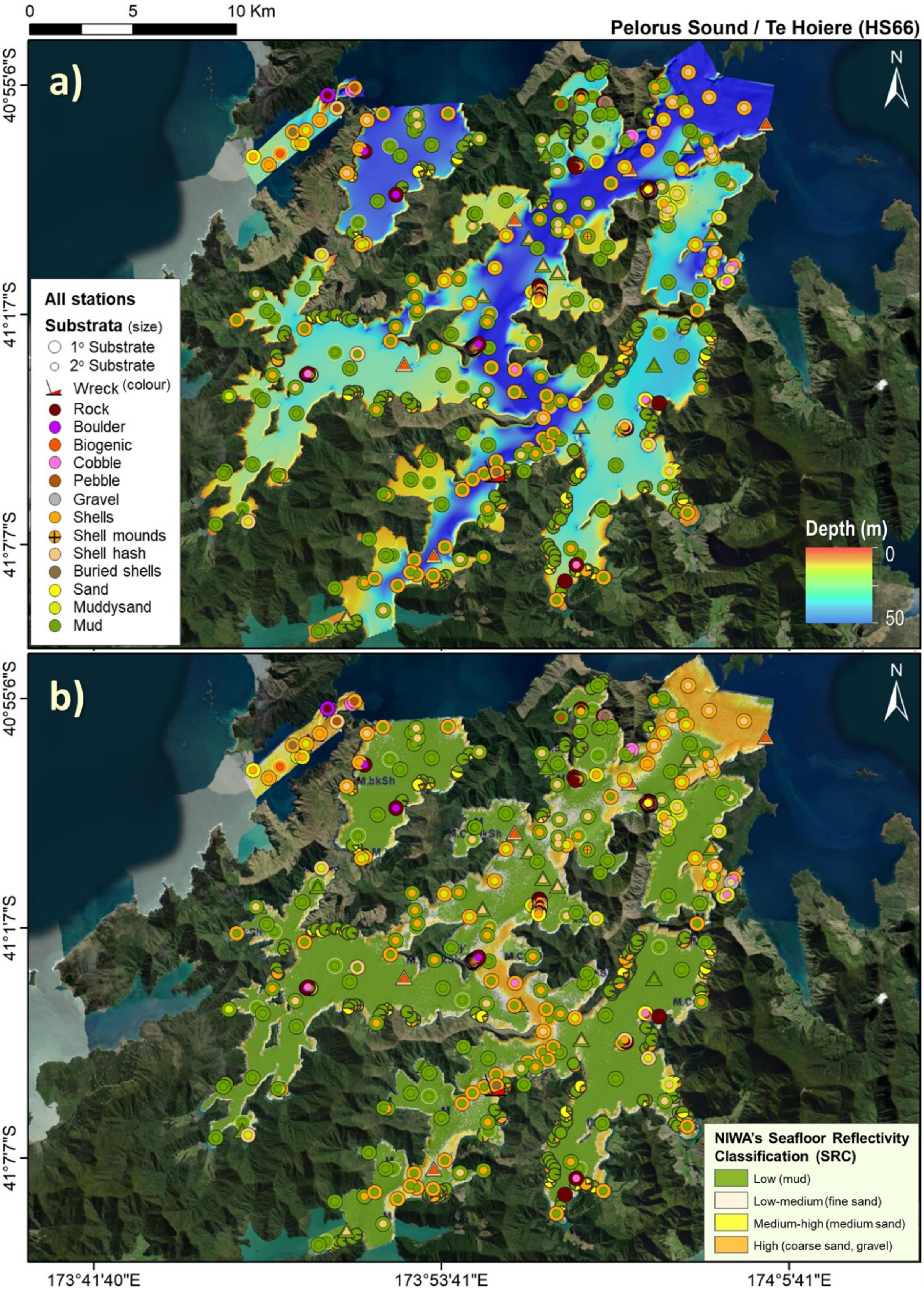

Figure 23. CBED classification for primary and secondary substratum types for all recent and historic ground truthing sites, overlaid on the HS66 a) bathymetry and b) NIWA's Seafloor Reflectivity Classification (SRC). CBed classes are for primary (large circles) and secondary (smaller inner circles) substratum type characterised based on recent ground truthing from HS66-2020 surveys (collected by NIWA, iXblue and DML) as presented in Appendix A-C in Orpin et al. (2020) and Rob Davidson 2021 reef surveys; while historic data is from Estcourt (1967) [triangles] and DSIR 1983 (McKnight et al. 1991a) [white 1° circles]. The SRC layer is a geo-rectified image of NIWA's preliminary SRC (Neil et al. 2018; Orpin et al. 2020).

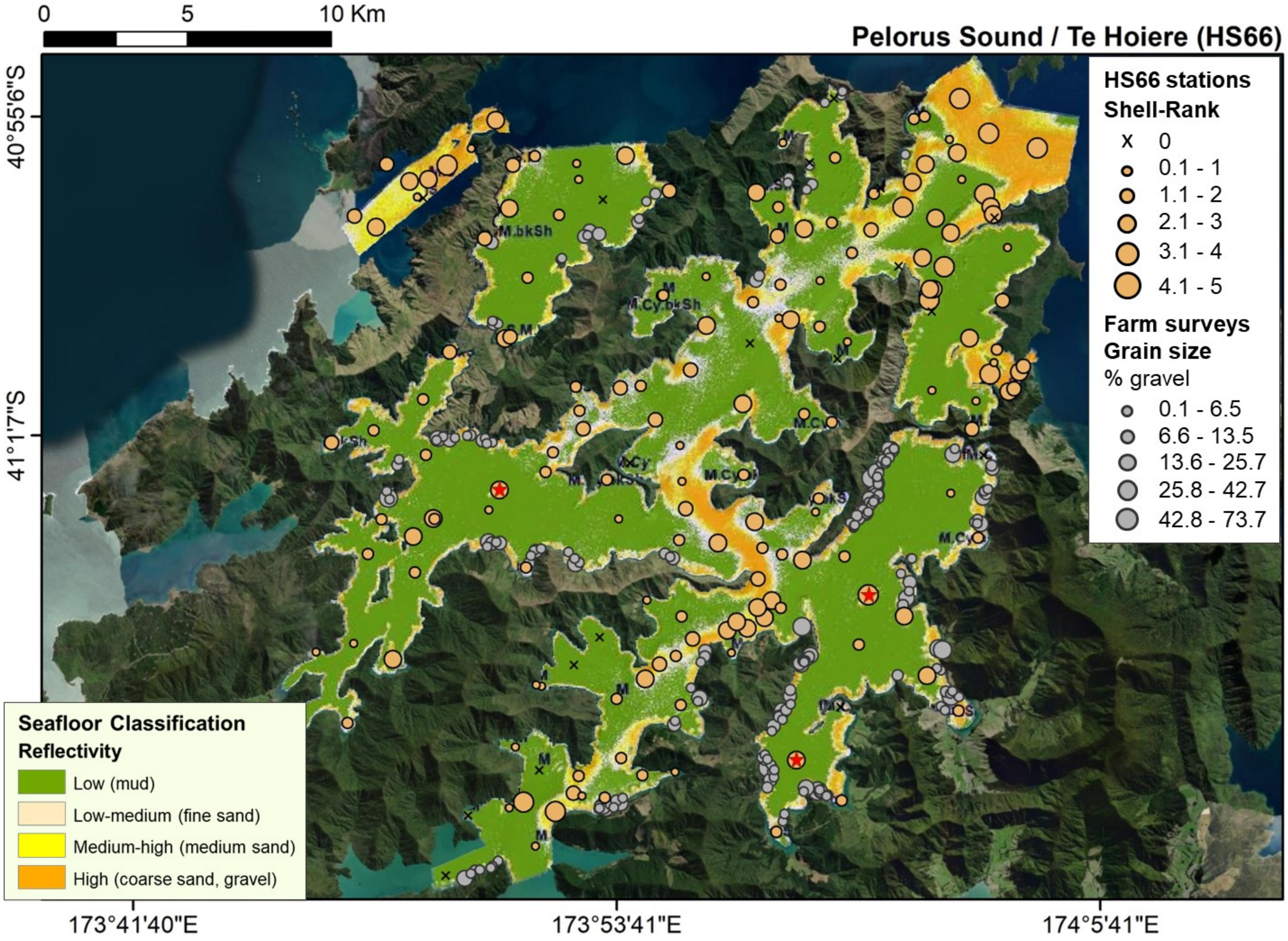

Figure 24. Shell debris rank for HS66-2020 ground truthing sites (based on descriptions from Appendices A-D in Orpin et al. 2020) and the % of gravel from gain size analyses of inside and outside farm sites within the HS66 survey area. Red stars = sites located on submerged raised reefs/banks (obscured by their bubble size), and therefore do not reflect the surrounding low-reflectivity sediments (green mud areas); Farm data are from MDC Aquaculture farm SmartMaps system.

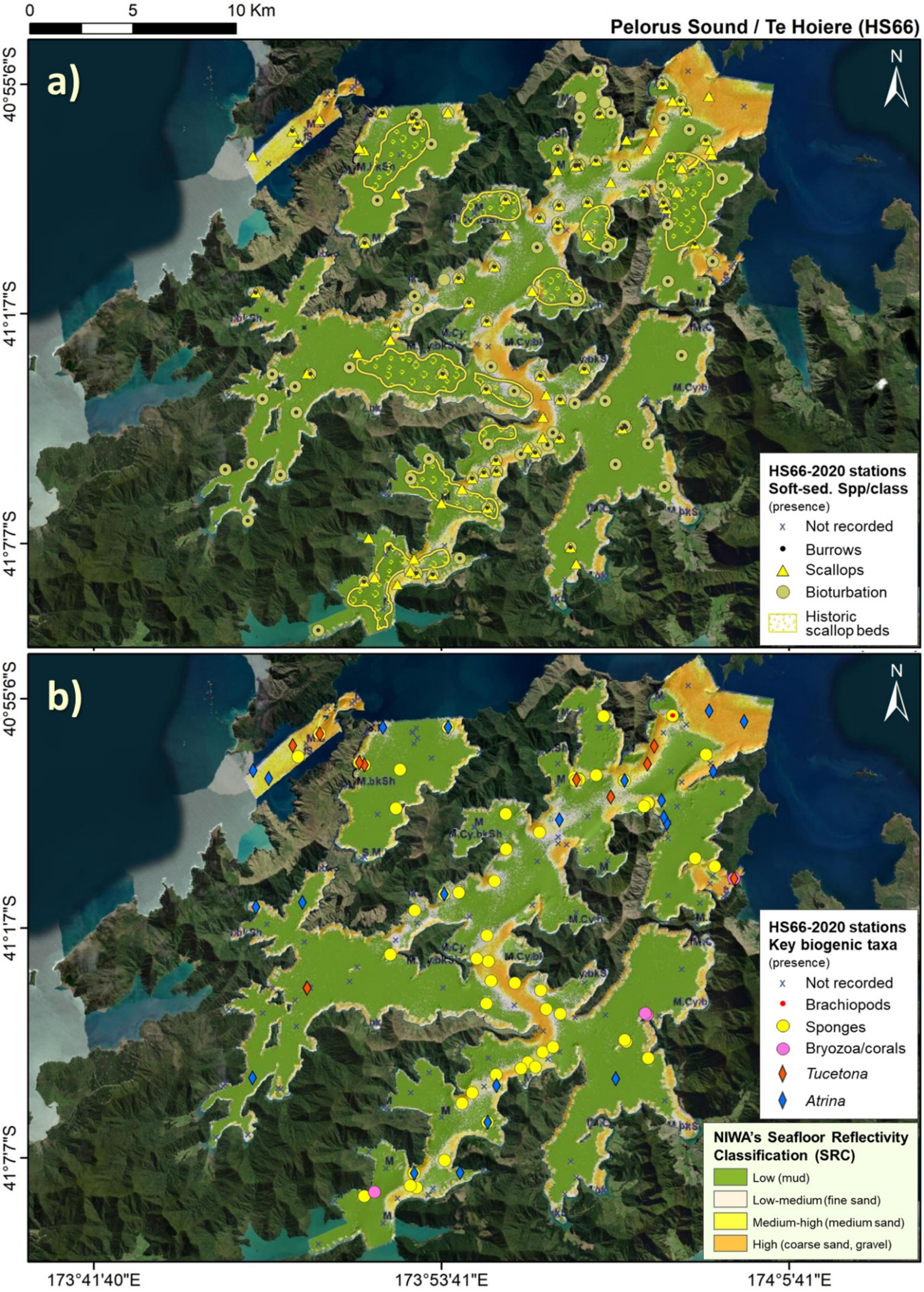

Figure 25. Presence of key taxa indicative of a) soft-sediment habitats, and b) biogenic habitat in HS66-2020 ground truthing sites, overlaid on NIWA's Seafloor Reflectivity Classification (SRC). Here, biota and lebensspuren (signs of bioturbation, incl. burrows) are from dropcam and sediment grab sites, as reported in Appendices A-D in Orpin et al. (2020), with soft-sediment taxa plotted relative to historic scallop bed locations (Handley et al. 2017); The SRC layer is a geo-rectified image of NIWA's preliminary SRC (as described in Neil et al. 2018; Orpin et al. 2020); x= no taxa reported, however these patterns should be used cautiously.

4.2.3 New knowledge around marine farms

Mapping seafloor habitats in and around marine farms is also an important area of research that can help determine the representativeness of different marine habitats that may be affected by various farming activities. Several localised small-scale habitat maps have been created for a few marine farms within the Marlborough Sounds, based on field-intensive benthic surveys (incl. various combinations of sediment grabs sampling, diver transects, and video-sleds), and localised-site multibeam bathymetry (e.g., Atalah et al. 2011a, 2011b; Ellis et al. 2011). Three habitat maps were georectified to assess i) how well localised maps might correlate with (and potentially ground truth) MBES layers, and ii) determine how well fine-scale habitat maps in conjunction with MBES layers might be used to extrapolate habitat information over much larger-scales. These habitat maps were from three sites within Waitata Reach in Te Hoiere/ Pelorus Sound – Waitata Salmon Farm (Ellis et al. 2011); Richmond Salmon Farm (Atalah et al. 2011b); and Kaitira Site (Atalah et al. 2011a) (Figure 26, *where all three localised habitat maps were created by Cawthron researchers).* Shell debris zones in the localised habitat maps appear to correlate relatively closely with the higher reflectivity zones in NIWA's SRC layer.

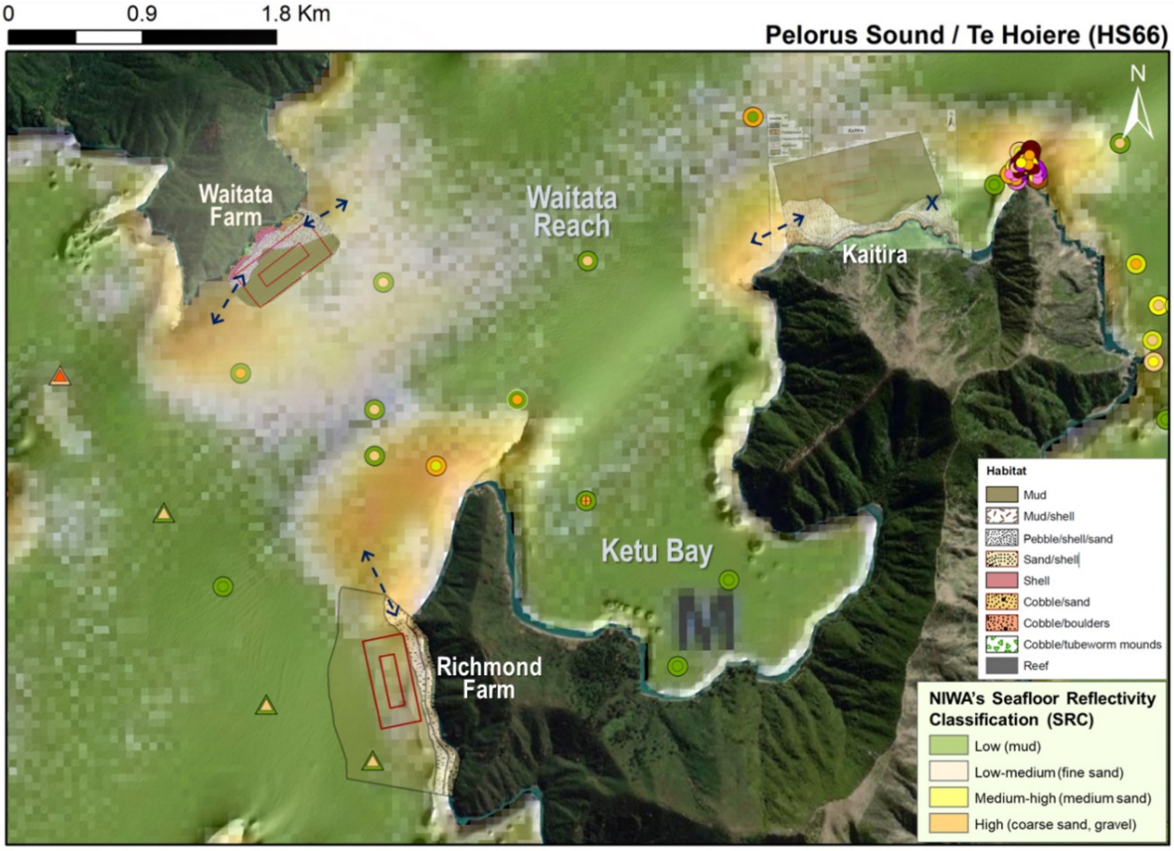

Figure 26. Cawthron habitat maps for Waitata and Richmond Salmon farm sites, and Kaitira (Pelorus South) (geo-rectified images from Atalah et al. 2011a, 2011b; Ellis et al. 2011), overlaid on NIWA's SRC. Habitat maps are semi-transparent; Blue dotted arrowed-lines indicate the relationship of the shell-debris zones in the habitat maps to the high reflectivity zones in NIWA's SRC layer; blue cross indicates no underlying shell-zone. Site locations (metadata) in and around farms has not been plotted here to avoid obscuring the maps, but each of these sites has considerable benthic sampling effort associated with them.

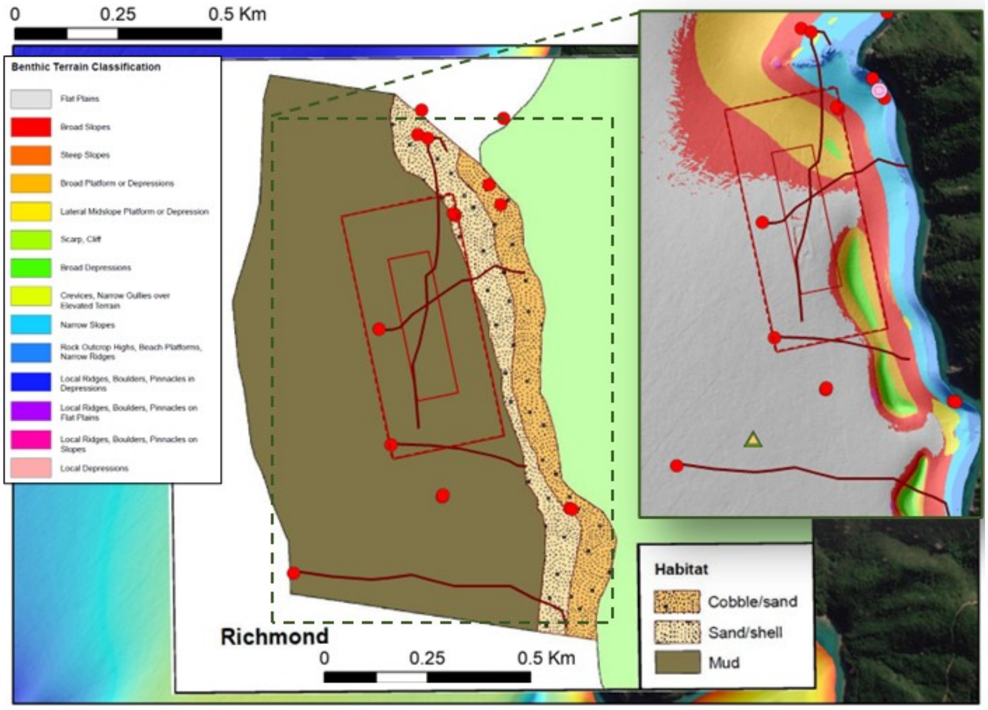

Figure 27. Seabed habitat map around the Richmond Salmon Farm site (Pelorus South) created by Cawthron researchers (details in Atalah et al. 2011b). Habitat map and red transect lines (depicting video transect lines) have been redrawn from geo-rectified tiff. Location of this site is indicated by the letter 'R' in Figure 9. Insert depicts the benthic terrain model classifications across Cawthrons mapped area.

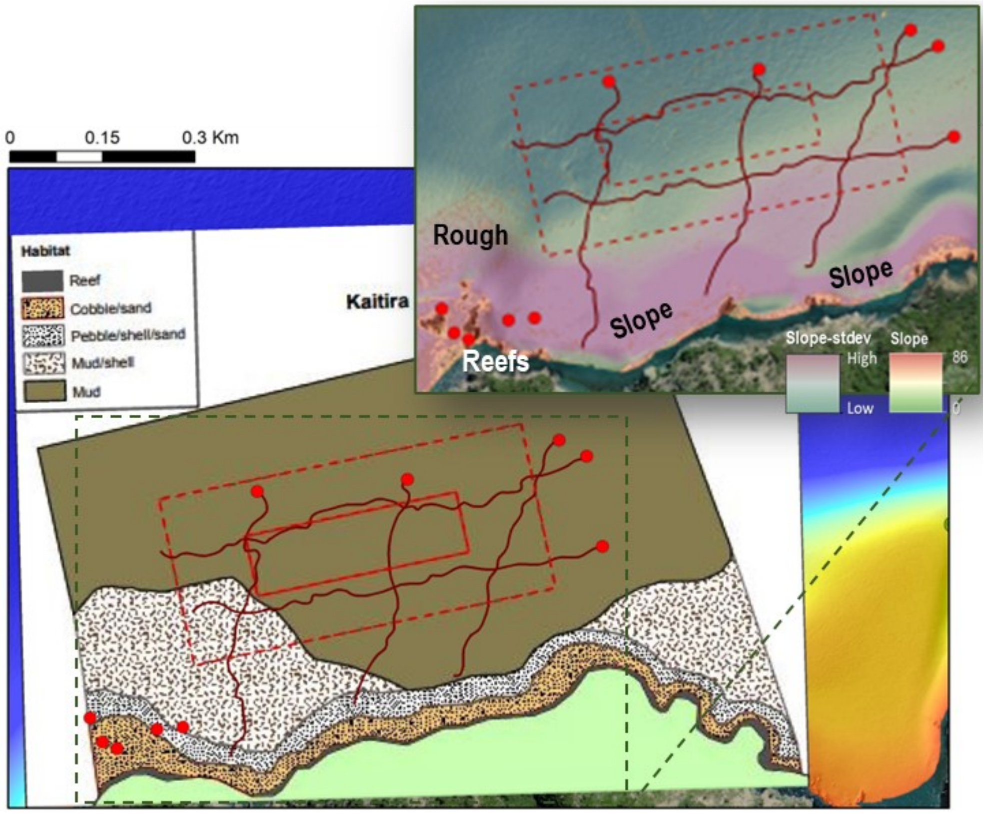

Figure 28. Seabed habitat map around the Kaitira Salmon Farm site (Pelorus North) created by Cawthron researchers (details in Atalah et al. 2011a). Habitat map and red transect lines (depicting video transect lines) are redrawn from geo-rectified images. Location of this site is shown in Figure 26. Insert depicts seafloor roughness (slope-stdev) overlaid on the slope, across Cawthron's mapped area. Here, MBES layers provides some additional fine-scale information to help potentially revise the boundary of the local Kaitira habitat map, although ground truthing video observations relative to these layers would need to be evaluated.

The combination of these MBES layers and the ground truthing data identifies that the higher reflective shell debris patches in and around these three sites (incl. the two farm sites) extend well beyond each of these sites, but, based on NIWA's SRC layer, these shell debris patches are still localised and predictable, as they appear to be associated with hot-spots of faster current speeds that occur near the seabed, around bends and change of channel direction along the Waitata Reach – and in similar location all the way along the main Te Hoiere/ Pelorus Sound Channel. This should be examined further by more detailed visual examination of these layers (particularly the current speed and SRC layers), and analytically if a raster layer of seafloor reflectivity classes can be attained. Other combinations of physical and environmental layers can and should also be examined to determine if their inclusion can provide additional predictive (and explanatory) information. Examination of NIWA's BTM classifications appear to show little correlation with the observed habitat types, bar changes in slope angles, at either large (no shown here) or fine-scales (e.g., Richmond Farm Site, Figure 27). However, rugosity and roughness (slope-stdev) did provide some valuable predictive information, that could also be used to help refine (and slightly correction) the existing localised habitat-map boundaries at these sites (e.g., Kaitira Site, Figure 28). Although only shell-debris habitats are examined here, this approach (and associated layers) already has considerable promise and significance as a management tool for assessing the likely impact of marine farming activities of benthic marine habitats, and already provides some realistic visual extrapolation across large-areas of seafloor.

4.3 MBES maps to predict significant biological sites

4.3.1 Bathymetry & derived benthic attributes (what can they tell us)

The difference in the shape and complexity across the seafloor can be valuable correlates (proxies/surrogates) explaining changes in habitat complexity, biodiversity and benthic community composition (McCormick, 1994; Gratwicke et al. 2005; Wilson et al. 2007; McArthur et al. 2009). Depending on the coastal environment and the community types present, various combinations of benthic terrain attributes may be important in predicting large-scale distributions and fine-scale boundaries of these habitats and community types. Derived attribute layers from the multibeam bathymetry, such as slope and rugosity, can provide critical information on the structure and configuration of the seafloor. Aspect, for example, measured as the angle of exposure from north at 0° to south at 180°, can be very useful proxy for exposure, particularly in a coastal environment, with variable exposure gradients. Hill et al. (2014) examined a range of MBES correlates for predicting benthic community types around offshore deep rocky reefs in south-east Tasmania. In this study area, south easterly winds and harsh swells were strong drivers of marine community and diversity patterns around these islands, with aspect found to be a good modelled-proxy for this exposure gradient. Marlborough Sounds also experiences strong gradients in exposure. However, when examining MBES correlates for predicting benthic marine community patterns within the Eastern Marlborough Sounds (i.e., The HS51 survey area), aspect provided little predictive value, especially where near-bottom current speed and other MBIE layers were included (Anderson, Anderson et al. 2020; Anderson et al. 2020; Anderson et al. 2021). In this system tidal-currents are an important driver of community patterns ((Anderson et al. 2020c), where the inclusion of near-bottom current speed negates the need/value of aspect. Therefore, while proxies can provide very valuable predictions, it's important to evaluate their value and their limitations.

At finer-scales, physical surrogates (incl., MBES layers) that may not correlate directly with biology, or be inconsistent across the whole map, may still have important contributions when evaluating local areas. For example, change in slope, aspect or curvature colours may indicate systematic changes in the shape of the bedform, and by doing so may help visually delineate the boundaries of a significant habitat. This is also the concept behind the BTM classification of geomorphology, whereby similar natural deviations (or breaks) in multiple attribute layers are used to detect and delineate geomorphic boundaries. However, as habitat and community-type boundaries may reflect a range of different boundary conditions, it is generally wise to evaluate these layers independently as well. Two layers of high relative importance in detecting and delineating seafloor habitats and their significant benthic communities were Rugosity and Slope-stdev, both separately, but also in combination (e.g., Figure 29 and Figure 30).

Figure 29. Comparison between seafloor rugosity (a) and the standard deviation of the slope (slope-stdev) (b) across the HS66 survey. Yellow dotted circles highlight areas of comparison, at large spatial scales, where slope-stdev provides significant addition information to the rugosity layer in terms of the roughness of the seafloor. This is very valuable as it can provide considerable insight into the presence of low-relief structure on the seafloor (white-red) such as living and relict biogenic habitats and cobble/rubble.

Rugosity (or roughness) of the seafloor is the ratio of surface area to planar area, and where combined with elevated seafloor features often represents hard rock outcrops. In the benthic environment, ecological-diversity is often correlated with environmental complexity, including high rugosity, as this often infers the presence of more micro-habitats/niches for animals to use. While rugosity is the deviation in the bathymetry that indicates rugose features (such as rugged rock outcrops), the **standard deviation of the slope (slope-stdev)**, is the deviation around the mean change in slope. This measure indicates fluctuations along a flat or sloping surface, and can be particularly useful in picking up variation that can infer seafloor roughness, that may depict rough debris fields (e.g., broken rubble and cobbles) and habitats composed of living and relic biogenic structure (e.g., bryozoan reefs and shell debris fields). In the HS51 survey, the standard deviation of the slope was extremely useful in identifying and delineating all three of these low-lying habitats: including: 'living' biogenic habitats (e.g., bryozoan patch-reef zones at the entrance to Queen Charlotte Sounds); shell-debris slopes (e.g., *T. laticostata* debris fields), and rubble fields (cobble and broken rubble) (e.g., Anderson et al. 2020a).

Qualitative assessment of the MBES-HS66 layers relative to available ground truthing data examining areas of high slope-stdev (here termed 'roughness') provide valuable insight into finer-scale seafloor structure and habitat configuration. Examining and comparison of rugosity and slope-stdev layers, identified the occurrence of different habitat zones, and provided very valuable interpretation of both seafloor patterns (habitat and community types present), but also help build an understanding of the physical processes (e.g., currents) driving these patterns.

A good example of this is an area of seafloor exposed to the Allen Strait current, in the area north of **Sugar Loaf Island** (Figure 30 and Figure 31). Looking at the rugosity and slope layers, overlaid on the hillshade relief (to give a 3D affect) (Figure 30a,c), one can see rock outcrops around Sugar Loaf Island and the wisp of mainland and submerged reef extending to Sugar Loaf Island, also with rock outcropping at various locations down the slope to the base of the seafloor. Bathymetrically distinct sediment wave formations are also discernible in the channel stemming from Allen Strait (indicated by the dotted arrowed lines in (Figure 30a), while mussel farm moorings, south of the land mass, are also discernible as small red features in the rugosity layer (Figure 30a). Overlaying the slope-stdev we see that there is a lot of roughness down these slopes, but also high amounts of roughness in the channel area associated with the sediment wave formations (Figure 30b). Overlaying the slope-stdev over the rugosity layer provides a very clear and realistic view of the seafloor, where by rock outcrops are visible (red areas), but also the duller red colour both down the slopes indicate rough slopes possible of cobbles and/or shell debris, as well as out over the sediment wave formations in the channel indicating an extensive area of debris-fields (Figure 30d). A site surveyed during the HS66 ground truthing campaign (HS66-2020 Site FB47, at 48 m), collected a sediment grab with 'muddy-sands and thick shell debris, with *Chlamys* and hermit crabs', while the dropcam identified that the rough-bottom was comprised of a thick layer of shell with some pebbles over muddy-sand, with "brittle stars and gastropods". Although there are no ground truthing sites down the slopes, ground truthing data from similar slopes elsewhere, were characterised by various mixtures of cobbles, biogenic rubble (incl. from broken *Galeolaria* frames) and shell debris that provide various levels of habitat complexity for other species.

Overlaying Maier et al.'s (2021) Benthic Terrain Classification (where colours depicted in Figure 30e represent different geomorphic features), identified that the 'rock outcrop' classification (i.e., blue coloured zone, class 10) accurately captures the general spatial location of the rock outcrops, but when zoomed in, looks a bit like a sloppy paint job, whereby the borders of these reefs are not well aligned with the predicted boundary of the rocky outcrop layer (Figure 30b). Conversely, the rough sediment waves present in the channel are not captured as a feature at all, instead the geomorphic classes of broad slope (red) and broad platform (tan) break this feature into odd sections (Figure 30e).

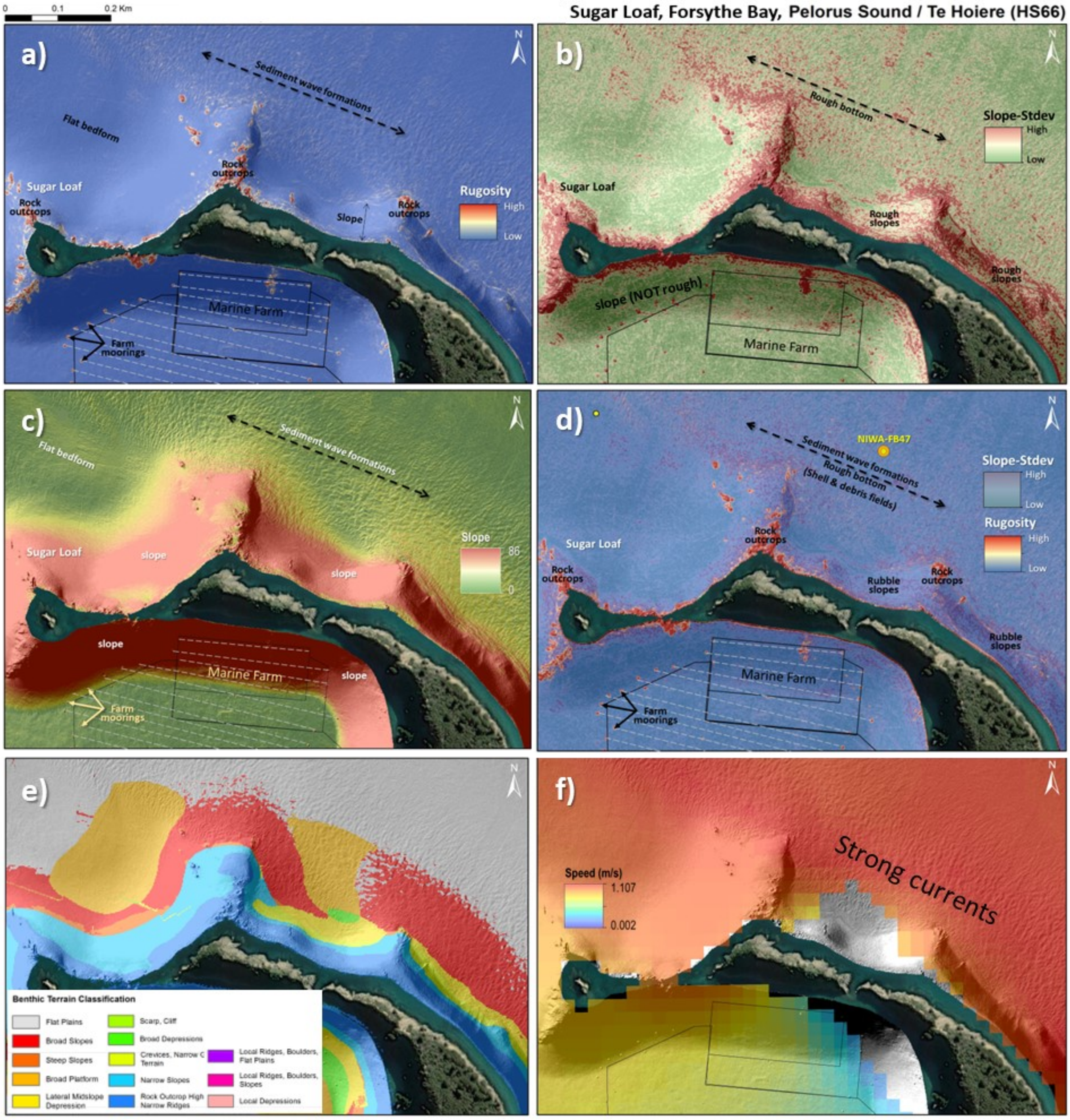

Figure 30. Example MBES-derived benthic attribute layers that can now be interrogated to qualitatively (and quantitatively) predict and delineate different benthic habitats - examined for Sugar Loaf Island, Pelorus north. . a) Seafloor rugosity (40% transparency) overlaid on the Hillshade relief. Red areas = high rugosity features (e.g., rock outcrops); b) Standard deviation of the slope (Slope-Stdev, 40% transparency) overlaid on the Hillshade relief. Red areas here depict high stdev (of the slope) and infer a rough seafloor; c) Slope terrain. Here red depicts high slope angles, while green depicts little to no slope; d) Combined seafloor rugosity (40% transparency) and Slope-Stdev (40% transparency) overlaid on hillshade relief. Here bright red areas depict high-rugosity (reefs and moorings), while the dull reddish colour beneath depicts predictively rough habitat surfaces - comprised of either cobble and shell rubble (e.g., on the slopes), and armoured shell rubble over sediment waves (e.g., out in the channel); e) NIWA's Benthic Terrain Classification, here colours predict different geomorphic features; f) Mean current strength at 5 m depth, based on NIWA's hydrographic modelling (Broekhuizen, Hadfield et al. 2015), here red areas= high current strength. A single ground truth sites (NIWA's Site HS66-FB47 with sediment grab and dropcam video) identified that the rough bottom area seafloor in the channel was comprised of a thick layer of shell with some pebbles over muddy-sand. Dotted grey lines between mooring blocks depict the location of mussel longlines at Farm LI-107.

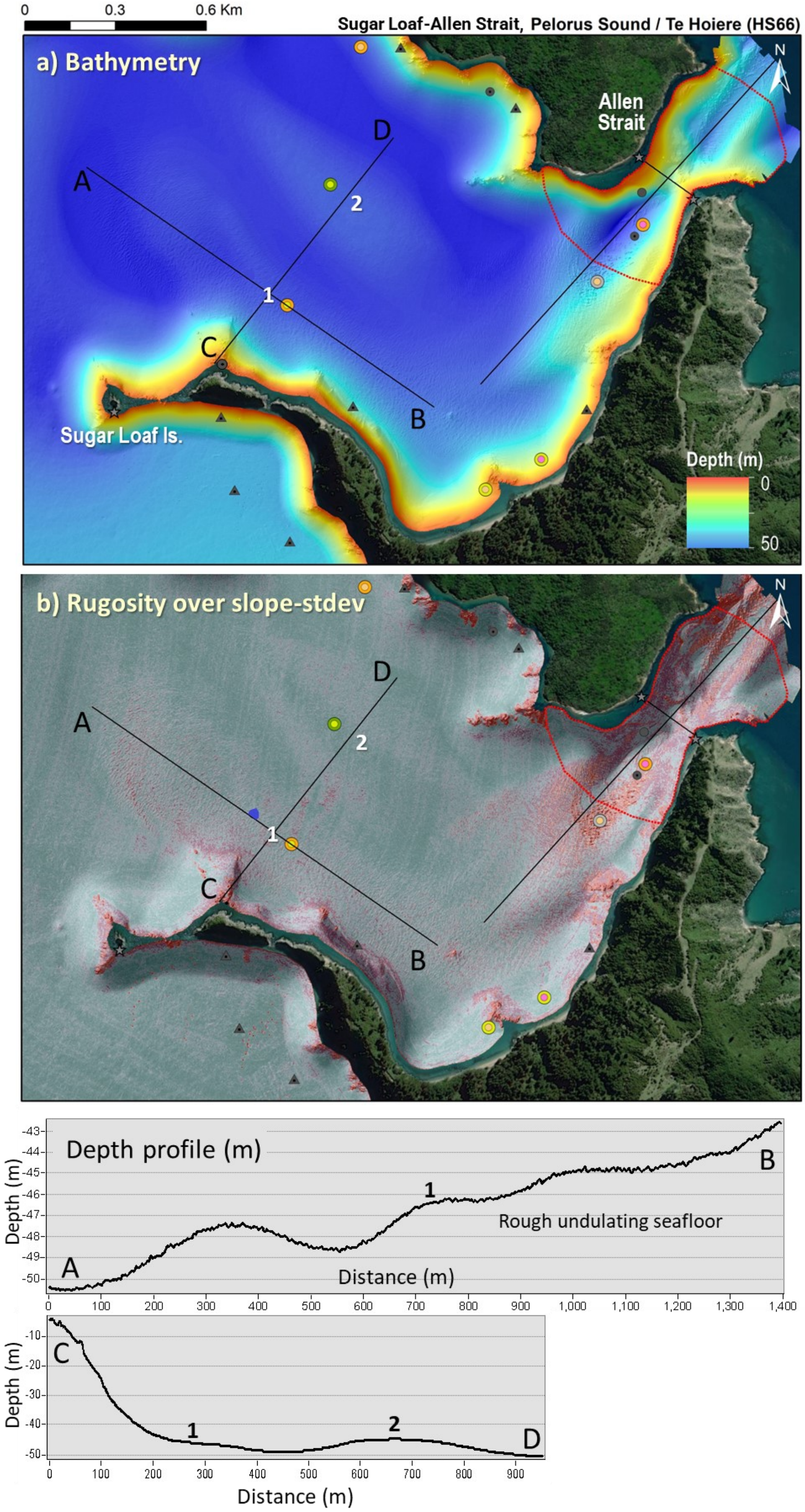

Figure 31. Depth-profiles along the seafloor channel north of Sugar Loaf Island (A-B), and perpendicular to shore (C-D), northern Pelorus Sounds. Numbers 1 and 2 are provide for spatial reference along and between depth profiles. See Figure 39 for depth profiles through Allen Strait.

Overlaying the mean current speed layer over these features (Figure 30f), identify very strong mean speed across the entire channel area generated by water forcing through the narrow Allen Strait (located <~1 km east of this seafloor channel), generating enough force to create and maintain this sediment waved zone (Figure 30f). Depth profiles along the length to the channel (Figure 31, insert) identified that channel morphology has two scales of bedform waves, with large-waves spaced approx. 250 m apart, overlaid by fine-scale sediment waves spaced ~5 m apart (Figure 31-insert). The depth profile perpendicular to the channel, indicated a broad channel (~300-400 m wide) with a raised central-bank in the middle of the bay. A ground truthing sample from the central bank (HS66-2020 Site FB45, at 47 m) reported sticky muds with bioturbation and patchy epifauna, with no mention of shell debris. Examination of the rugosity and slope-stdev layers at the larger scale of the bay (not shown here), identified a measurable a 'rough-channel zone' 1.5 km long by ~350 m wide.

The rugosity and slope-stdev attribute layers, both provide valuable information in isolation, however, the combination of these two layers provides considerably more inference to help differentiate biologically-relevant habitat types. For the Sugar Loaf-Forsythe Bay example, the combination of all six MBES layers (Figure 30) along with the intersecting perpendicular depth profiles (Figure 31) identifies how each of these layers provides additional information that together provides a much more insightful interpretation of the seafloor. However, it is an important reminder that while these attribute layers provide considerable inference with respect to the shape and composition of the seafloor, these interpretations still require on-the-ground (i.e., ground truthing seafloor samples and/or video observation) to verify these interpretations.

Rugosity and seafloor roughness (slope-stdev) in combination, can also provide valuable insight into the composition of raised features. For example, within Pelorus South, several raised submerged features were mapped. For example, in Crail Bay two submerged raised ridgelines were mapped. A large ridgeline (~913 m long, 181 m wide and 17 m in height) in 30 m water depth in the middle of Crail Bay, SW of Te Puraka Point (here referred to as Deep Reef 1: *maps in* Figure 32); and a second smaller raised feature (~228 m long, 66 m wide and 5 m in height) also in 30 m water depth in the southern section of Crail Bay, SW of Ouokaha Island (here referred to as Deep Reef 2: *maps in* Figure 33). Based on reviewing the LEK polygons relative to the new HS66 map layers, it appears that Deep Reef 2 is the feature referred to as polygon 36 in Jones et al. (2016) (as depicted in Figure 43, *but also see* Section 4.4 below, *and a more zoomed-in map in* Figure 48). As with the Sugar Loaf Island example, examination of the various MBES-HS66 map layers, helps infer not only the geomorphology, but also the likely composition of habitat types across these two features. For Deep Reef 1, the rugosity layer (Figure 32c) in combination with the bathymetry and slope maps (Figure 32a,b, respectively) indicates that exposed rockout crop appears to be limited to the narrow upper ridge line of this feature. Seafloor roughness (slope-stdev: Figure 32d) builds on this picture, by showing higher levels of roughness a narrow zone directly below this rocky ridgeline – indicating possibly a cobble-rubble like zone, while the remainder of the slope is much less rough – characterised by "bioturbated muds, with small burrows and tracks, scallops and some shells" (*based on ground truthing site descriptions in* Orpin et al. 2020). The MBES map layers for Deep Reef 2[11], indicate that this much smaller raised feature, has a few exposed rock outcrops along its highest points (Figure 33a,b), while its' gentle slopes appear to be covered in mud with some scallops and shells (Figure 33*c*). These examples, show how valuable the MBES map layers are, for not just mapping the spatial location and shape of these features, but enabling excellent insight into the types of habitats that are likely present; and also, how even just a few ground truthing samples can provide good confirmation of inferences made based on the interrogation of these maps.

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[11] This raised feature is likely the area referred to by long time fishers as 'Rough Ground' drawn as LEK polygon No. 36 in Jones et al. (2016).

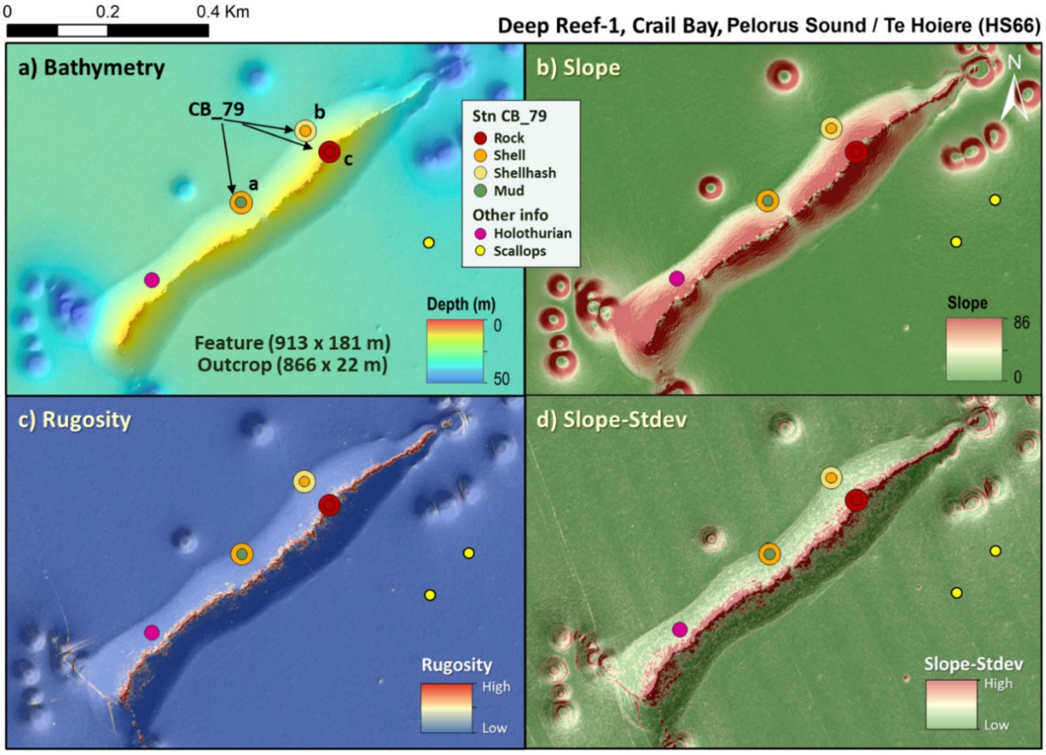


Figure 32. Raised feature (913 x 181 m in size, ~17 m in height), referred to here as 'Deep Reef 1' beyond the entrance to Crail Bay, Pelorus Sounds. a) Bathymetry showing a slight mote at 30 m, around the base of this feature; b) Slope, red = high slope (angle of ~ 6°) on the central and upper slope regions, ~3° down the lower slopes, cream = gradual slope (<2°) down the lower slope and around the base; c) Rugosity, red = areas of high rugosity inferring a narrow rock outcrop (13-22 m wide) extending 913 m along the top of the feature; d) Seafloor roughness (Slope-stdev), red = high rugosity (rocky outcrops) and a zone of rough seafloor (indicative of low lying rubble) extending ~37 m down slope of the rock outcrops. Holothurian = *Pentadactyla longidentis*.

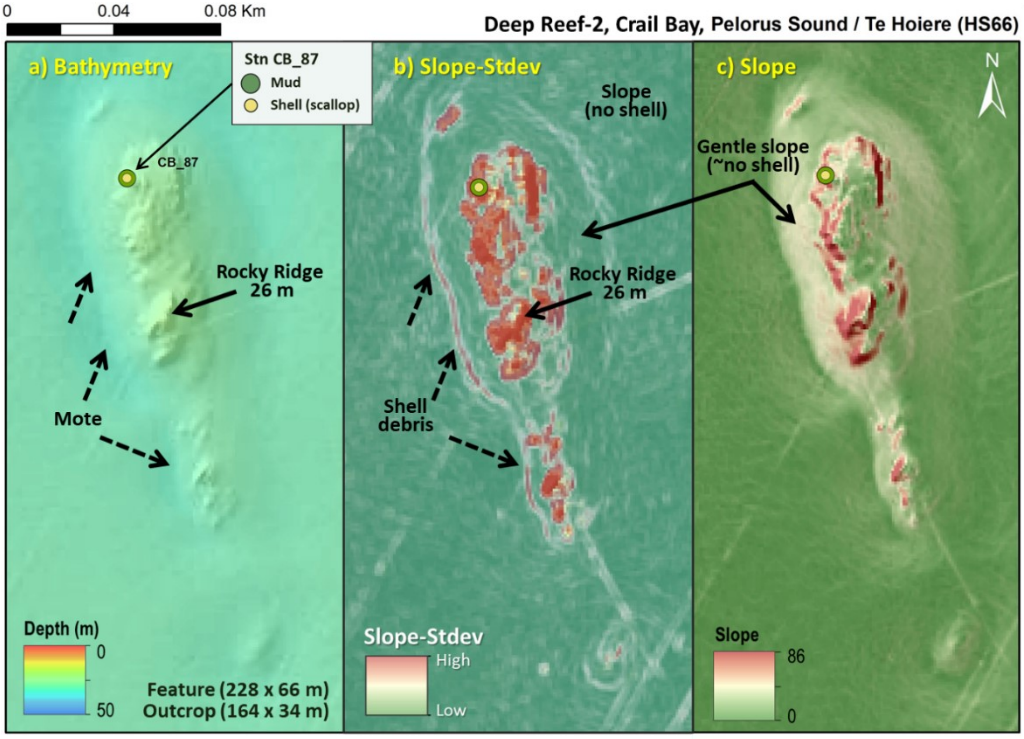


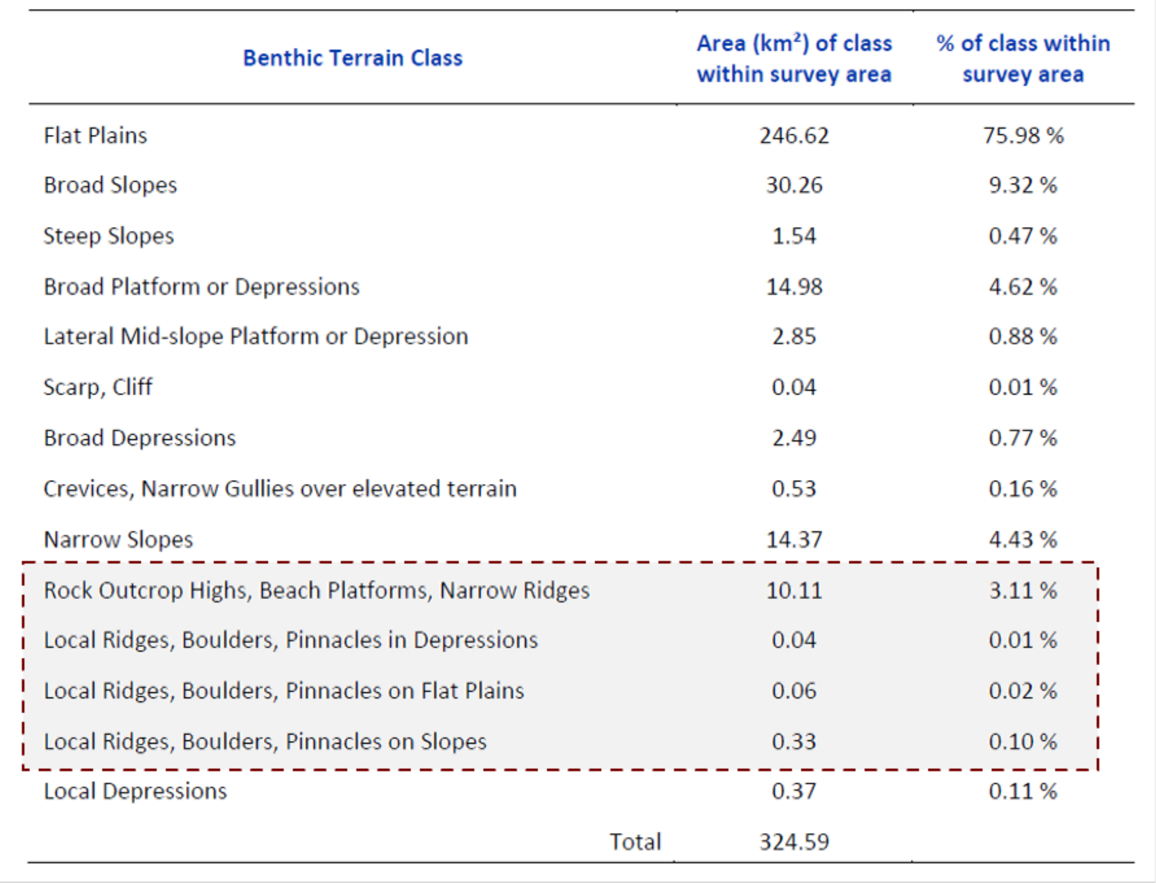
Figure 33. Raised feature (228 x 66 m in size, 5 in height), referred to here as 'Deep Reef 2' in the centre of Crail Bay, Pelorus Sounds. a) bathymetry of the feature identifying a slight mote around the base of the feature at 30 m; b) Standard deviation of the slope (Slope-stdev), red denoting high rugosity and rough seafloor (indicative of rocky outcrops and debris covered seafloor); c) Slope, red denoting high slope areas around the raised rock features, cream indicates a more gradual slope down the banks of the feature.

4.3.1.1 NIWA's Benthic Terrain model Classifications

Benthic Terrain Modeller in ArcGIS is a valuable tool to delineate different geomorphic features. These models look at points on the MBES map layers and compares them to adjacent points further away to determine changes in shape of the seafloor. The model then uses the relationships between all of these layers (e.g., depth, slope rugosity, slope-stdev) to delineate different geomorphic zones (e.g., Wright et al. 2012). Benthic terrain modelling was undertaken for both the HS51 and HS66 survey areas, using the same methods (Neil et al. 2018; Maier et al. 2021). These user-defined generated 14 geomorphic classes (Neil et al. 2018; Maier et al. 2021; list of classes is provided in Table 5). These classes included flat plains, three different types of slopes (broad, steep and narrow), three different types of depressions, rocky outcrops and three types of pinnacle features (based on the location within a slope, plain or depression). BTM output classifications can provide useful insight in inferring types of benthic habitats and species distributions, but only where these classifications accurately align with these features (*i.e., how well the model boundaries align with the features they are attempting to model*), and, where these geomorphic classifications correlate meaningfully with benthic habitats and their associated communities. Neil et al. (2018) states that the classification scheme used in the HS51 survey "*underpins a benthic-habitat map*", "*with each class predicted to have distinct environmental conditions",* and can inform future targeted photographic and bottom-sampling programmes.

All of these things are correct to some degree. However, the correlation between geomorphic features and biological-relevant habitat types, depends on a number of factors, which need to be explicitly evaluated to determine how well these classes act as proxies for benthic habitats. For example, in the HS51 survey in the eastern Marlborough Sounds, the BTM classified rocky features across the region. This classification generally aligned well with observed rock features at large-spatial scales (based on the available high-resolution bathymetry and ground truthing observations) and included rock features from sheltered inner Sound areas in water depth < 10 m to exposed offshore rock pinnacles out in Cook Strait in water depths >100 m. However, these various forms of rock categories each reflected different reef sizes and complexities that supported different biological communities with different levels of biodiversity and naturalness. Here a combination of depth, currents, exposure, slope, rugosity and substrata type together were critical in predicting these different rock-associated communities. In this example, the BTM variable in isolation of these other spatial gradients did not capture this complexity, and therefore, provided little predictive power beyond the initial derived variables of slope, rugosity etc. alone (Anderson et al. 2020a,b). At fine spatial scales, the BTM classification also failed to classify some rock outcrop on the deeper slopes, some of which supported rare clusters of crayfish or newly discovered *Galeolaria* mounds. Slope and plain boundaries as delineated in the BTM were also found to have little to no boundary relationships in common with any of the biological communities identified in the ground truthing. For example, even distinct biological boundaries seen in the ground truthing surveys that aligned well with changes in seafloor morphology and reflectivity (e.g., *Amphiura*-dominated soft-sediment communities) were not aligned with BTM classes. Categorical classifications can be useful approaches and definitely allows one to visualise shared boundaries between MBES layers, but these should not be considered direct proxies for benthic habitats, rather they should be interrogated and evaluated carefully to determine their relative value as predictors of benthic habitats and ecological complexity. A more thorough assessment of the value of the BTM classifications at more localised scales is required.

Table 5. Benthic Terrain Model Classifications (BTC) created by NIWA using ArcGIS BTM toolbox, and then used to calculate the area and percentage of total survey area for each of the 14 geomorphic classes. Based on *Table-1 in* Maier et al. (2021), with the rock outcrop (Class 10) and the three pinnacle/ridges layers (11, 12 and 13) highlighted by the grey box.



Benthic Terrain Class	Area (km^2) of class within survey area	% of class within survey area
Flat Plains	246.62	75.98 %
Broad Slopes	30.26	9.32 %
Steep Slopes	1.54	0.47 %
Broad Platform or Depressions	14.98	4.62 %
Lateral Mid-slope Platform or Depression	2.85	0.88 %
Scarp, Cliff	0.04	0.01 %
Broad Depressions	2.49	0.77 %
Crevices, Narrow Gullies over elevated terrain	0.53	0.16 %
Narrow Slopes	14.37	4.43 %
Rock Outcrop Highs, Beach Platforms, Narrow Ridges	10.11	3.11 %
Local Ridges, Boulders, Pinnacles in Depressions	0.04	0.01 %
Local Ridges, Boulders, Pinnacles on Flat Plains	0.06	0.02 %
Local Ridges, Boulders, Pinnacles on Slopes	0.33	0.10 %
Local Depressions	0.37	0.11 %
Total	324.59	

4.3.1.2 *Rocky outcrops layer*

Neil et al. (2018) created two 'second order classifications' for the HS51 survey area, one for rock outcrops, the other for seeps. The rock outcrops layer was created in ArcGIS based on "*the combination of positive curvatures (including plan and profile curvatures) coupled with high ruggedness over multiple resolutions of the combined bathymetry grid*" (Neil et al. 2018). However, while it appears a rock outcrop classification was calculated as a test for the Admiralty Bay region (Maier et al. 2022, ArcGIS Project files), along with high rugosity proxies for rocky areas, no rock outcrop layer was created for the HS66 region. Rock features within the Sounds are often spatially limited and often occur in high-current conditions where they support diverse species. Consequently, the creation of a rock outcrop layer for the HS66 survey would aid in the identification of these habitats.

The HS51 Rocky outcrops layers adequately captured most large raised ridges and reefs, but missed or inadequately delineated other smaller and often deeper rocky reefs (T. J. Anderson, Stewart, et al. 2020). The rock outcrops layer was an important layer in modelling habitat suitability for *Galeolaria* mounds, as it enabled other sediment layers to be cropped by this rock outcrop layer. This is important as NIWA's SRC layer does not distinguish hard shell and gravels from hard rocks, so a combination of MBES layers are required as used by (Neil et al. 2018).

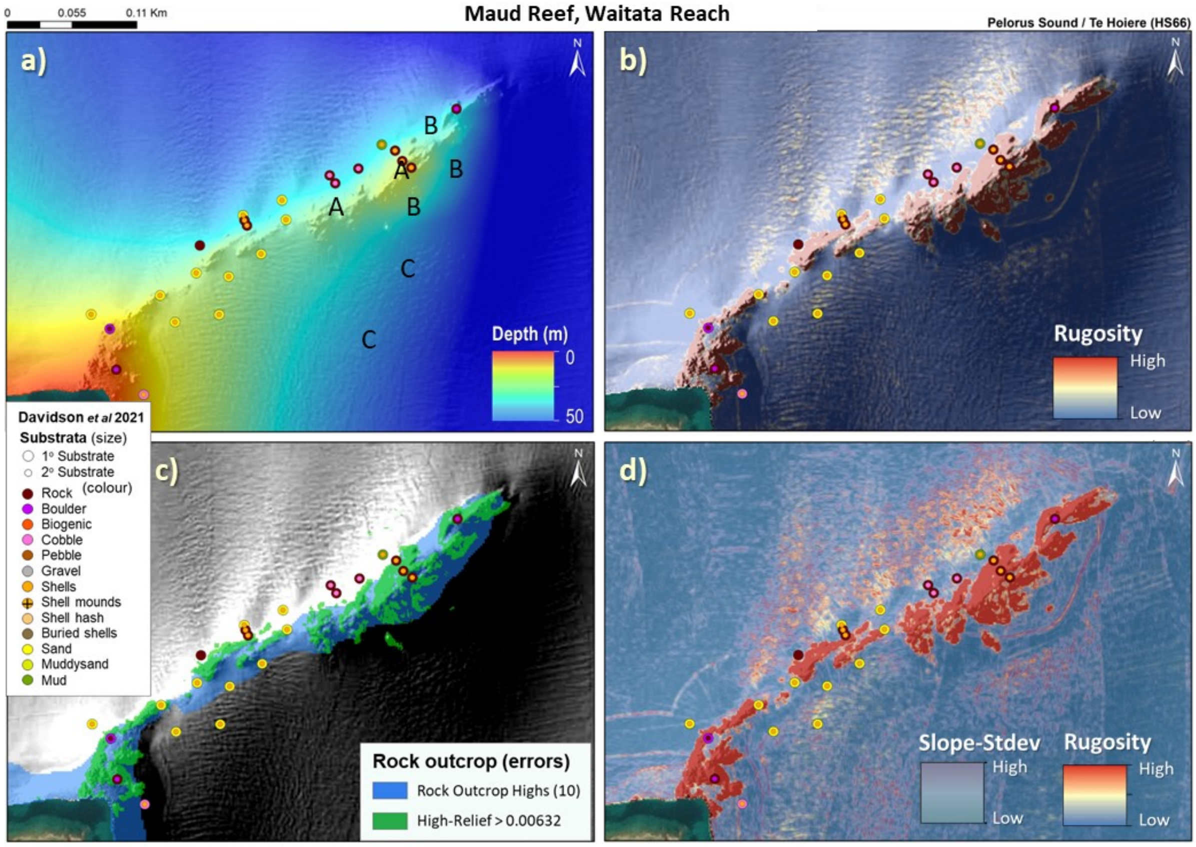


Figure 34 Evaluation of 'rock outcrop' measures for Maud Island ridge, Waitata Reach. . a) Seafloor bathymetry depicting raised ridgeline / rock outcropping feature, which extends out into the main Pelorus Sounds / Te Hoiere channel. Predicted habitat zones A-C: A=predicted/verified "current-swept rocky ridge with sponges"; B= predicted / possible *Galeolaria* zone; C=Predicted/possible *Thyone* spA zone. b) rugosity (40% transparency) draped over Hillshade relief (Red areas = high rugosity features / rock outcrops); c) comparison between Benthic Terrain Model Class 10 as a predictor of rock outcrop (blue zone) vs a Rugosity threshold value (green zone); d) Standard deviation of the slope (Slope-Stdev, 40% transparency) overlaid on seafloor rugosity (40% transparency) – here dark red = rock outcrop, light red = rough (likely shell debris) over sediment wave fields. Ground truthing sites were collected by R. Davidson in 2021-2022 using a drop camera system, and recoded by CBed 1° and 2° substratum types; These sites likely have some (unknown) layback/positional error due to currents and depth.

Close visual examination of individual rock outcrop features enables some preliminary evaluation to assess how well the Benthic Terrain Model classification of 'Rock Outcrop Highs' (class 10) actually aligns with high relief rock features. For example, examination of Maud Island Reef (here called Maud Reef) - a ridgeline that extends 436 m (18-64 m wide) out into Waitata Reach/the main Pelorus Sounds / Te Hoiere channel (Figure 34) -finds that while class-10 does depict the large-scale shape and length of this rock feature (blue colour in Figure 34c), it does not provide a 1:1 match with the actual fine-scale shape of this reef (e.g., green zone[12]), and at this finer-scale areal-estimates of this outcropping reef (included in Table 5) incur an error of poss.~40% (Figure 34c). Although high rugosity threshold values do seem to capture the actual fine-scale shape of this reef (Figure 34b), it also includes non-reef area at the base of this ridgeline - which appears to reflect 'sediment wave fields' (with elevated bathymetry, and both higher rugosity and roughness), which if used would also result in notable classification errors. This identifies that finer-tuning of threshold values is required to improve this fit.

Existing ground truthing has found deep reefs in high-current areas within the HS66 survey area to support a high diversity of species, dominated by filter-feeding species, including hydroids, compound ascidians, anemones and sponges (Davidson et al. 2022).

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[12] The green 'rock-zone' has been calculated as a preliminary threshold value for higher rugosity reef habitats – this appears to fit well, but requires more assessment.

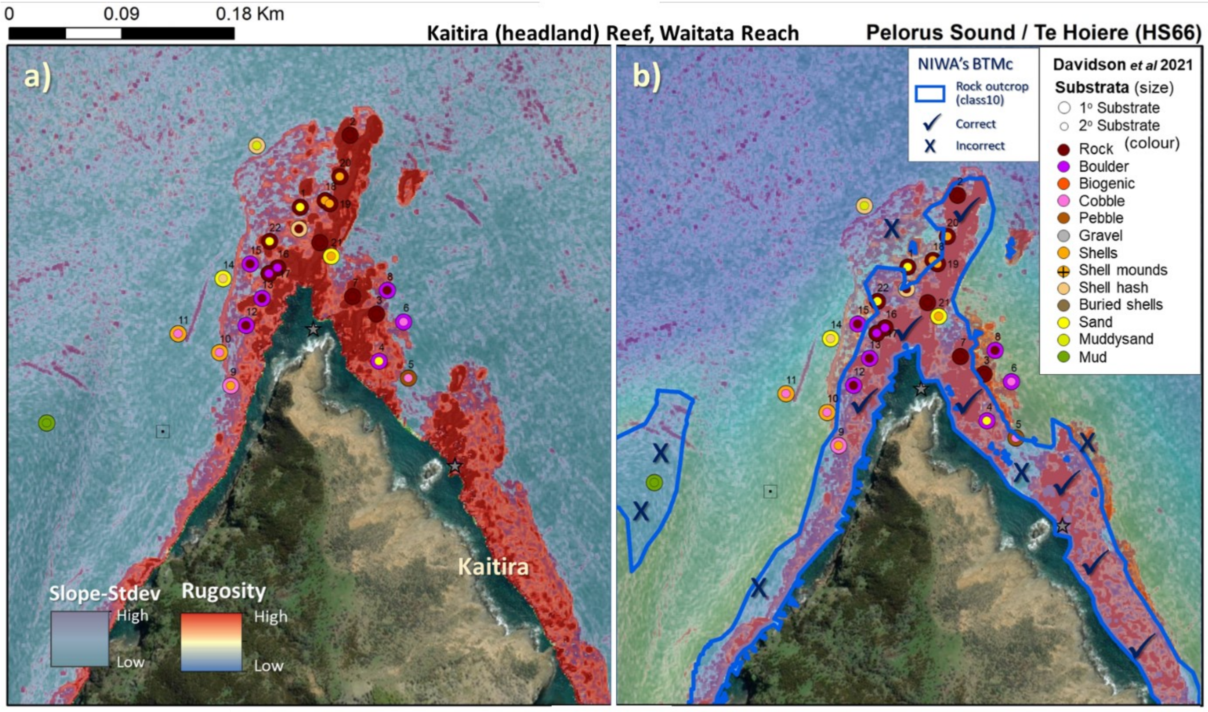

Figure 35. Evaluation of 'rock outcrop' measures for Kaitira Reef, Waitata Reach. . a) Seafloor rugosity overlaid on Slope-stdev. Here dark burgundy areas depict high relief reef habitats, while lighter burgundy colour based on ground truthing depicts rough area comprised of various mixtures of shell-debris, cobbles, boulders and sand. b) NIWA rock outcrop layer (Benthic Terrain Model [class 10] = '*Rock Outcrop Highs, Narrow Ridges*') overlaid on the same image as (a). Ticks and cross assess the spatial accuracy at this fine-spatial scale (<1 km). Ground truthing sites were collected by R. Davidson in 2021-2022 using a drop camera system, and recoded by CBed 1° and 2° substratum types; These sites likely have some (unknown) layback/positional error due to currents and depth. At the large-scale this 'rock outcrop layer does well, but at finer scales incorrectly denotes reef where only a raised mud bank occurs (left side of image b), and does align in 1:1 with the boundaries of the reef feature.

A 'verified' rock outcrop layer will assist with knowing the accurate location, shape and areal extent of deeper rocky reefs, and in turn will be important in identifying the locations and relative amounts of these rocky reef associated communities. The relationship between rock outcrops (size and rugosity) and the near-bottom current speed will also enable some evaluation of whether biodiverse current-swept communities are likely present. Based on preliminary examination of ground truthing data relative to MBES layers and newly reported sites in Davidson et al. (2022), it is likely that all ridge-like rock outcrop features that protrude out into the main current-swept channel in Pelorus Sounds / Te Hoiere support significant current-swept communities. In addition, these communities are likely to differ with distance into the sounds (poss. level of sedimentation), with inner Sounds rock outcrops predicted to support hydroid-tree dominated communities (e.g., the reef at the northern headland of Penguin Bay: MBES-2017 site CB17-PSC21, *pers. obs*.), while outer sounds reefs would be predicted to support current-swept communities dominated by sponges (e.g., Richmond, Kaitira and Keep Clear Reefs).

4.3.1.3 New 'roughness' layer

In addition to examining the best approach to creating a best-fit 'Rock Outcrop' layer, a range of layers and classification thresholds were examined to assess how to best capture biological-relevant structure in the MBES layers – that more directly represent seafloor habitat types. Two other 'second order classification' layers could be included that represent two levels of roughness that best represent the rubble and shell-debris (rough) zones around many reef and

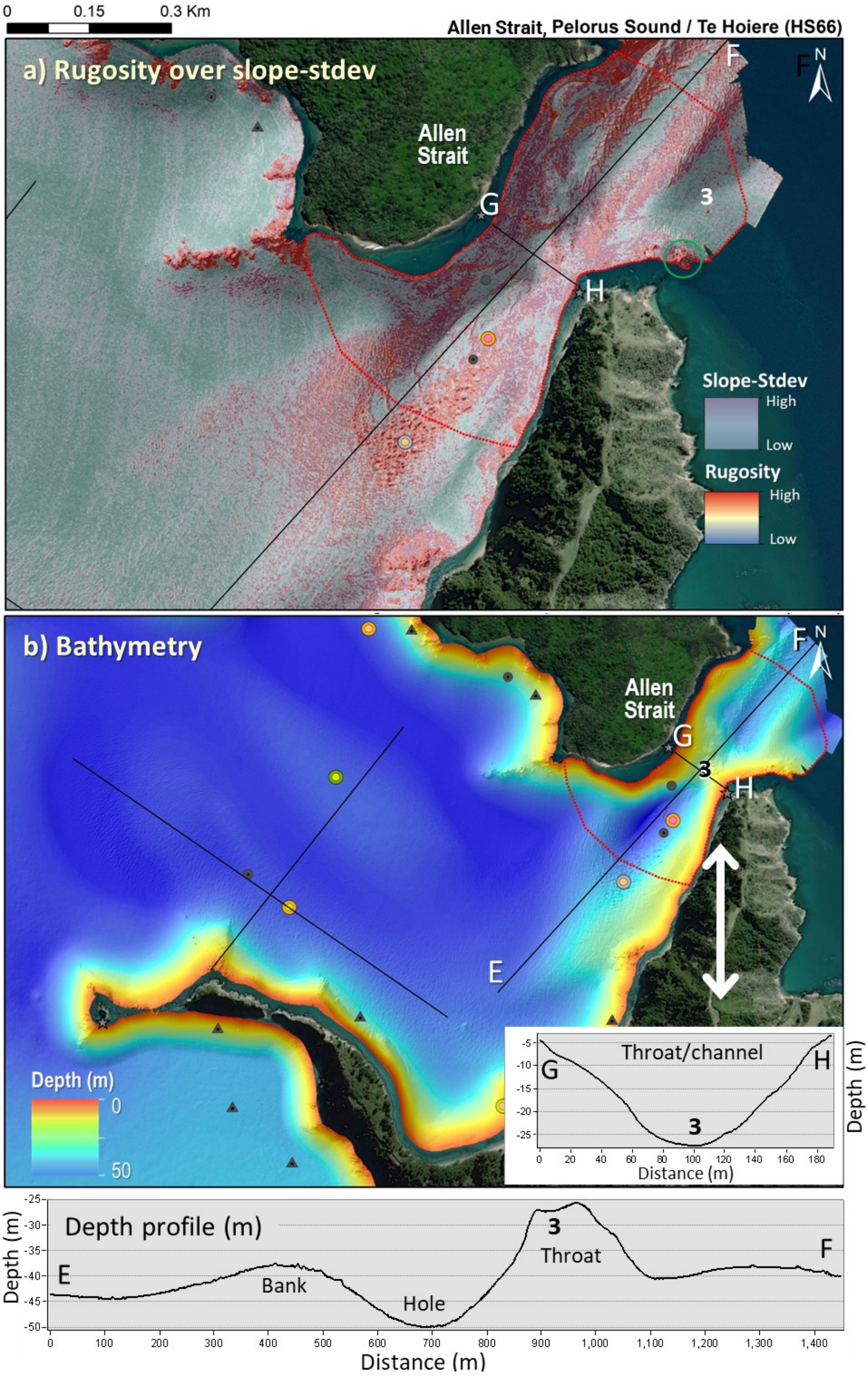

Figure 36. Depth-profiles through Allen Strait (EF) and perpendicular to shore (GH), northern Pelorus Sounds. a) Rugosity (65% transparency) over Slope-stdev; red area depicts areas of high rugosity and/or roughness; b) bathymetry; Inserts show depth profiles along (E-F) and across (G-H) Allen Strait. Number ‘3’ depicts the central ‘throat’ of Allen Strait and is provide for spatial reference along and between the two depth profiles. This combination of information provides an excellent landscape view of the seafloor through Allen Strait.

sediment wave form features. The development of these additional classification approaches could be a valuable method to help delineate these biologically-relevant ‘rough’ seafloor zones, and together with a refined rock outcrop layer, would be a valuable tool for MDC to meet their management objectives.

The development or adjustment of any classification layer in the HS66 survey area should also be considered in the HS51 survey area. This will ensure consistency between the eastern and western Sounds, and any predictions made between and across them, that adjustments to classifications in one area be examined and included in the other region too, or at least these comparisons should be kept in mind.

4.3.2 Backscatter (infers seafloor composition: soft vs hard)

MBES bathymetry and the derived benthic attributes of slope, rugosity and slope-stdev, etc, can provide valuable information on the shape of the seafloor, however, the addition of backscatter provides interpretation of the likely composition of that seafloor (range of hard to soft) that when combined with the bathymetry, along with the bathymetry-derived benthic attributes, greatly enhances the ability to interpret, distinguish and delineate seafloor features and their substratum types (mud, sands, gravels and rock) (Lamarche et al. 2011; Lurton et al. 2015). The combinations of these MBES layers enable many different types of geomorphic features to be qualitatively, and quantitatively (where models/relationships have been well validated) inferred. For example, flat or elevated smooth surfaces (devoid of rugosity) could be soft-sediment composed of muds or coarser sands, hard flat rock, or a sediment-veneer over a hard surface. With both the bathymetry and backscatter, these habitats should all be distinguishable – but not so, without the backscatter. Where bathymetric surfaces are elevated, higher rugosity and slope-stdev may provide some valuable inference for harder substrata, however, the intensity of the backscatter relative to these other MBES layers provides a much better understanding of what these seafloor bedforms are composed of (e.g., Figure 37). The relative spatial patterns in the various MBES layers also provide inference into the geomorphology, and the underlaying geology of these features. For example, in a survey of Cook Strait, Lamarche et al. (2011) was able to interpret a series of ‘contrasting black and white bands lying in a northerly direction’ in the backscatter with no associated bathymetric change, as contrasting seafloor deposits.

Both NIWA’s SRC layer and the mosaiced backscatter imagery (i.e., from even the rough ‘field-processed’ backscatter imagery) provides valuable information to help evaluate likely habitat types across these new HS66 region. For example, the geo-rectified image of NIWA’s backscatter layer for the HS66 area already provides valuable information to visually identify and delineate some important seafloor habitats (e.g., predicted ‘new’ areas of bryozoan patch-reefs; and current-swept communities associated with shell-debris field in Pelorus North subregion)[13]. .

Backscatter imagery and reflectivity data are also incredibly useful when sediment composition varies across a raised feature. In the HS66 survey area, several raised features were identified that appear to be veneered in sediment to varying levels. For example, a large raised bank within Ngāwhakawhiti Bay [Godsiff Bay], Tennyson Inlet, is clearly discernible in the bathymetry as being 1 km long (in an offshore direction) by <200 m wide, with a bathymetric change from 5 m depth inshore to 25 m depth offshore (Figure 38). However, although the bathymetry shows this to be a complex, albeit somewhat smooth, submerged raised feature, it has no high rugosity areas that might indicate rock outcrop.

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[13] Although, higher relief features are probably more accurately modelled using the near-bottom current speed and seafloor rugosity and / or rock outcrop layers

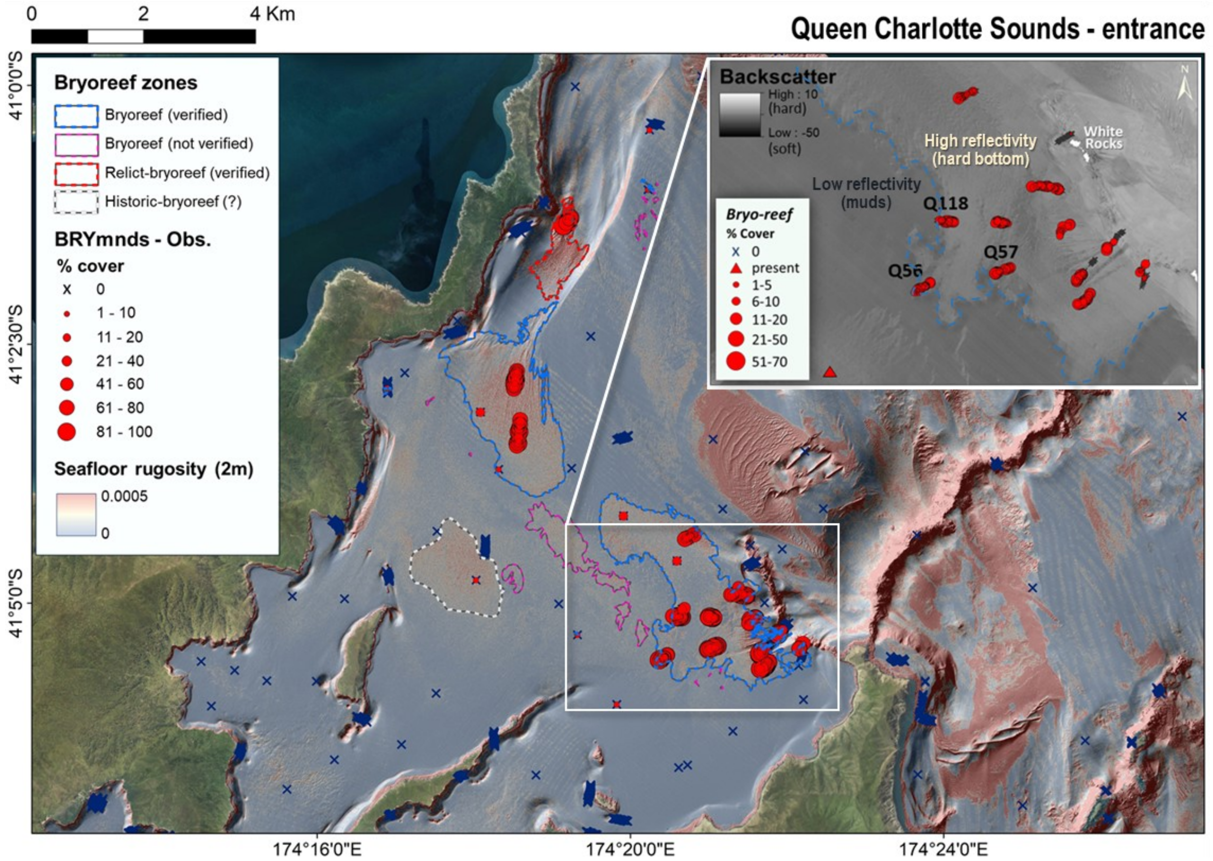


Figure 37. Example of how rugosity and backscatter helped delineate bryozoan-patch reefs at the entrance to QCS (HS51 region). Main image shows seafloor rugosity, with higher rugosity areas depicted in red; Insert shows seafloor backscatter, where lighter-grey areas depict higher reflectivity surfaces (inferring hard bottom habitats). This figure is a composition *from Figure 3-15 in* Anderson et al. (2020b) and *Figure 16 in* Anderson et al. (2020c).

No preliminary mosaiced seafloor backscatter imagery is available for the Pelorus South subregion, therefore, no review or evaluation of the backscatter imagery (and inferred composition) could be made. Three ground truthing sites have been surveyed over this raised feature: two sites during the recent HS66-2020 ground truthing campaign, and one dredge site, sampled back in 1983 (*site positions and substrata type are shown in* Figure 38). These observations identified three different habitat types: 1) mud on the western slope (HS66-2020, SS-016, Sediment grab sample only); while the top of the bank was described as having 2) muddy sand with some rock, the later incl. coralline algae and macroalgae (DSIR-1983, T554, 18 m, dredge sample - identifying this site position will be representative of a much large dredge-area); and 3) shell-debris with muddy sand, with tracks and burrow – indicative of a very thick veneer of sediment over this part of the feature (HS66-2020, TI-Reef, 14 m, grab and dropcam). However, the seafloor habitat observations from these three ground truthing sites do not directly align with any characteristic in the bathymetry or bathymetry-derived benthic attributes. The relatively smooth flat top of this feature has no high rugosity indicative of rock outcropping, yet rock has been recorded. Thus, this feature is a good example of where having the backscatter imagery would likely help to determine where rock is exposed versus where and how much of this feature is draped in depositional sediment (and/or accumulated shell-debris), and would also likely help indicate the relative thickness of sediment (inferred from changes in backscatter strength) across this feature.

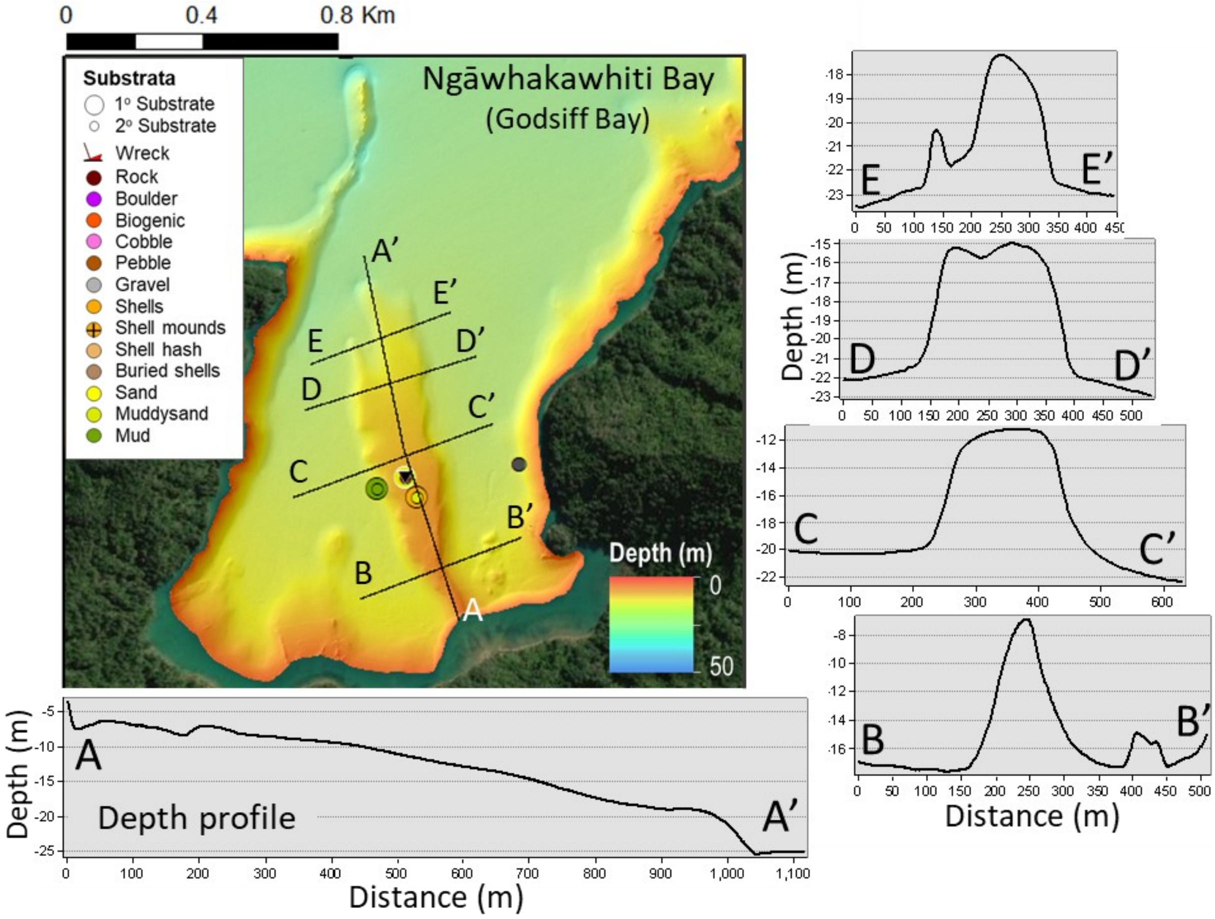


Figure 38. Example of a raised bank-like feature in Ngāwhakawhiti Bay (Godsiff Bay), seen here in the HS66 bathymetry draped over the hillshade relief. Lack of available backscatter imagery for this feature, makes inferring where rock outcrops versus heavily veneered sediment occur difficult, with the exception of the three ground truthing sites (see text for details) which identify spatial variability between mud (green circles), muddysand and rock (burgundy), and shell and muddysand (light-yellow). The location of depth profiles, is depicted by letters. Black triangle = Museum sample (metadata). Here, the triangle lies over the DSIR site (T554) - indicating that a museum sample for this site exists.

4.3.2.1 Visual (qualitative) interrogation of backscatter

Qualitative (visual) assessment of backscatter reflectivity maps, along with other bathymetrically-derived MBES layers, has already aided our ability to distinguish habitat zones and delineate the discrete or transitional boundaries of many different habitat types within the HS51 survey area. These support significant marine communities with high biodiversity (T. J. Anderson, Stewart, et al. 2020). Qualitative assessment of backscatter was important in defining and delineating habitat boundaries for: bryozoan patch-reef habitats (*Chapter 3.2.2 of* Anderson et al. 2020c); *Galeolaria hystrix* tubeworm mounds (*Chapter 3.2.3 of* Anderson et al. 2020c); burrowing sea cucumbers (*Thyone* spA) (*Chapter 3.2.4 of* Anderson et al. 2020c); deep buried-debris slope (cup corals and/or brachiopods) (*Chapter 3.3.4 of* Anderson et al. 2020c); and seafloor plains (*Amphiura*-dominated communities) (*Chapter 3.3.6 of* Anderson et al. 2020c).

In the HS66 region, the preliminary processed iXblue backscatter (i.e., field-level processing only) for four of the five sub-regions, although roughly processed for the purposes of determining where to place ground truthing samples, already provides considerable (first pass) information. When this backscatter imagery is combined with the bathymetry, benthic attribute layers (slope, rugosity, roughness, etc.) and the known organism-habitat relationships from the HS51 region, the location of new significant habitats within Te Hoiere/ Pelorus Sound can be predicted.

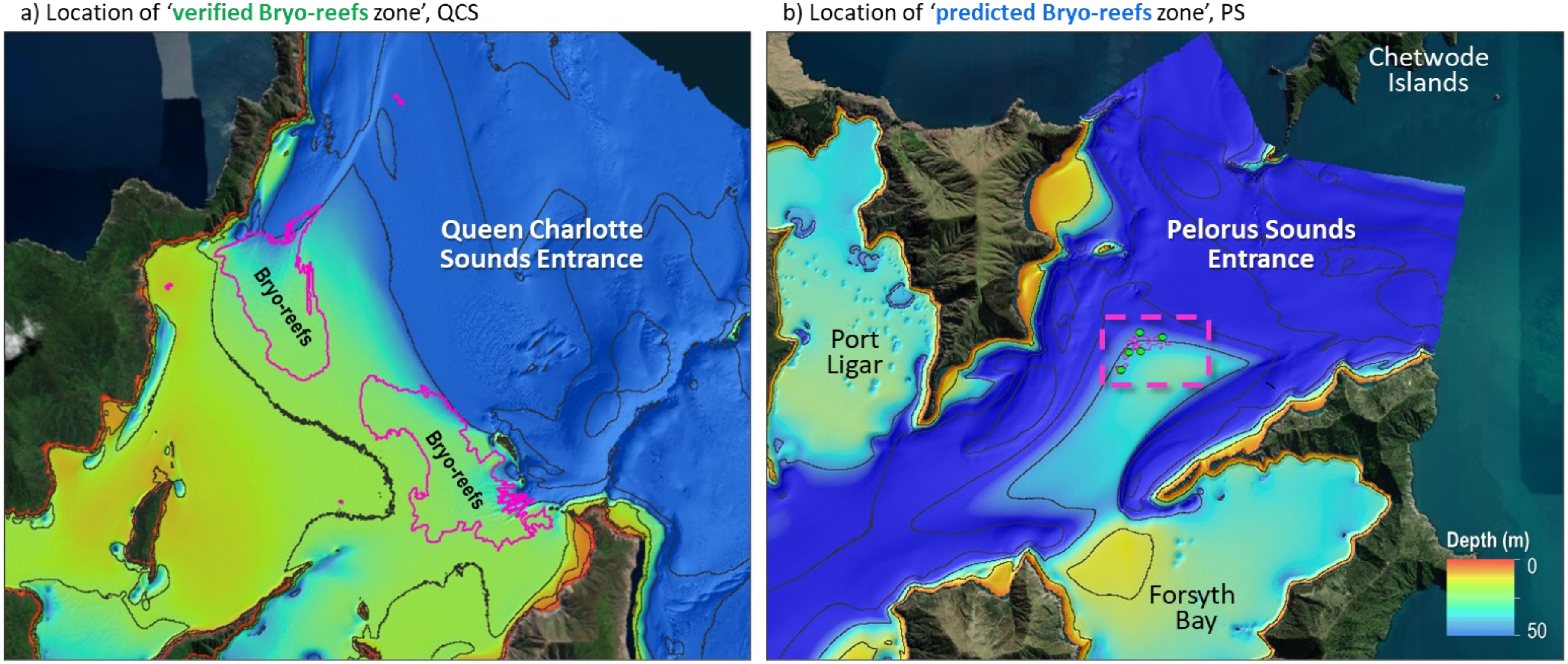
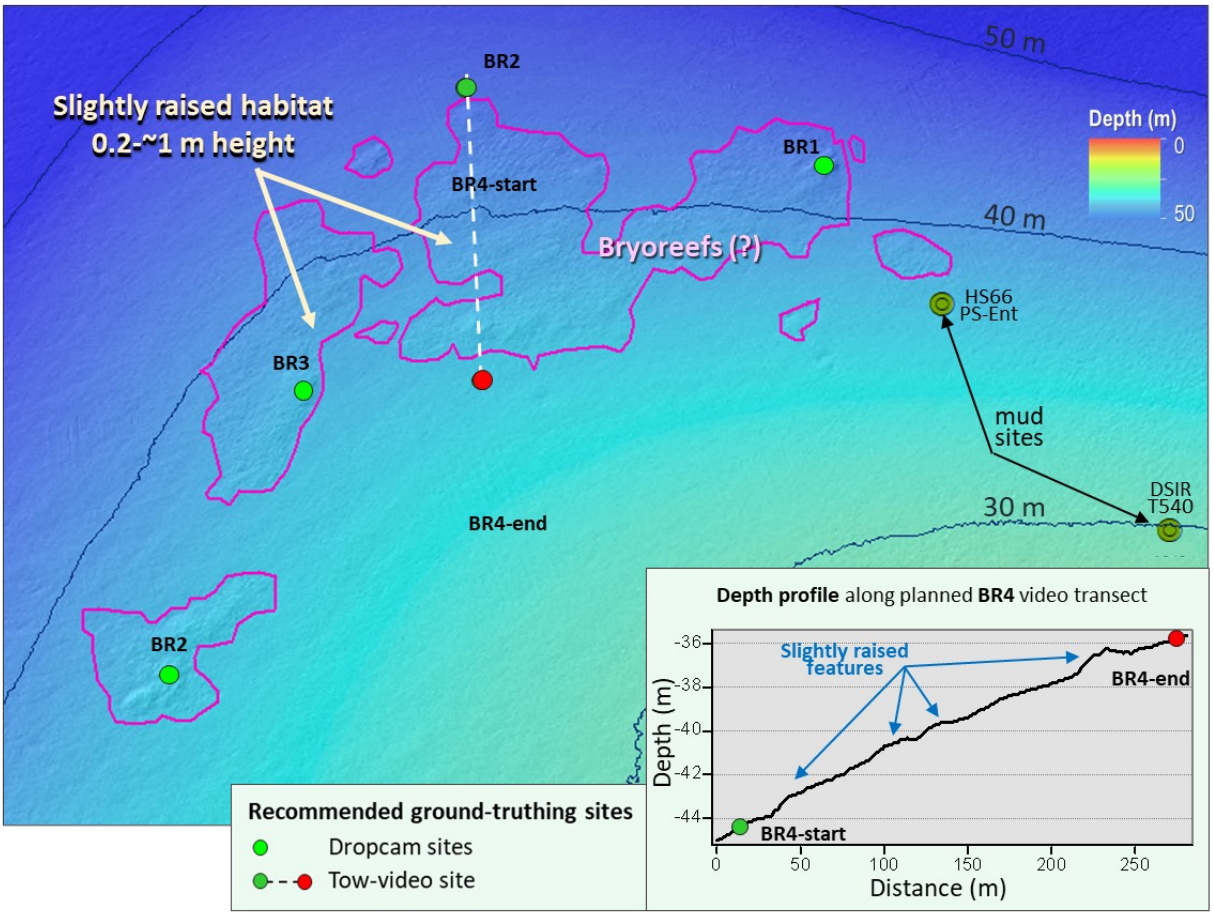


Figure 39. Location of a) verified significant 'Bryozoan patch-reef zones', s the entrance to QCS; and b) Predicted location of their occurrence on a similar current-swept bank at the entrance to Pelorus Sounds. Pink line in (a) are the delineated boundaries of the verified bryozoan boundaries in QCS; Pink dashed rectangle in (b) is examined in more detail (zoomed-in) in Figure 41 and Figure 40.

A key example here, is the extensive bryozoan patch-reef zones that were discovered in 2018 - across the raised bank at the entrance to QCS (Figure 39a; Anderson et al. 2020c, 2020b). This significant biogenic habitat supported rich benthic communities dominated by the reef-forming Tasman Bay coral, *Celleporaria agglutinans,* along with other habitat-forming (e.g., other hard bryozoa, large erect sponges, hydroids and ascidians) that in turn provide mostly low-lying, but complex structural habitats for a diverse array of sessile and motile fauna (Anderson et al. 2020c), in otherwise soft-sediment banks. These biogenic habitats are also important nursery habitat for juvenile blue cod (Morrison et al. 2014; Anderson et al. 2019, 2020c; Anderson *in prep*.). Bryozoan patch-reef zones in QCS were only discovered during the MBES ground truthing towed-video surveys (T. J. Anderson, Stewart, et al. 2020), but due to their close correlation with visual changes in several MBES-HS51 layers (i.e., low-negligible bathymetry; low rugosity, high slope-stdev, and high backscatter reflectivity (hard bottom)), these layers were able to used to delineate the boundaries of these zones (Anderson et al. 2020c, 2020b).



Recommended ground-truthing sites
● Dropcam sites
●- - ● Tow-video site

Figure 40. Zoomed-in area where bryozoan-patch reefs are predicted to occur, based on raised bathymetry in depths of 35-45 m and MBES layers, at the entrance to Pelorus Sounds. Here, new ground truthing sites have been designated to verify this prediction. Insert is the depth profile along the white dotted line of the planned towed-video transect – indicating that these raised features (which are hard and rough), are generally low-lying with high off the seafloor measured at 0.2-1 m in height. These seafloor characteristics were representative of bryozoans in the entrance to QCS.

Preliminary examination of the MBES-HS66 maps in ArcGIS identified similar features, indicating that a similar bryozoan patch reef zone may occur on the raised bank within the entrance to Te Hoiere/ Pelorus Sound (Figure 39b; Figure 41 and Figure 40). In this example, this new 'predicted-area' of bryozoan patch-reef was able to be delineated using the same visual assessment, and, even the MBES-HS66 raw mosaiced backscatter imagery (from iXblue), provide some valuable visual verification that these features were harder (i.e., more reflective) than the surrounding muddy sediments (existing HS66 ground truthing data, Site PS-ENT-26 and DSIR 1983 dredge survey site T540). These sites now require targeted ground truthing[14] to verify the presence of bryozoan patch reefs here in Pelorus Sounds / Te Hoiere, and their health and value as a significant marine site. Where these new areas are confirmed, it would establish greater generality of these predictive relationships.

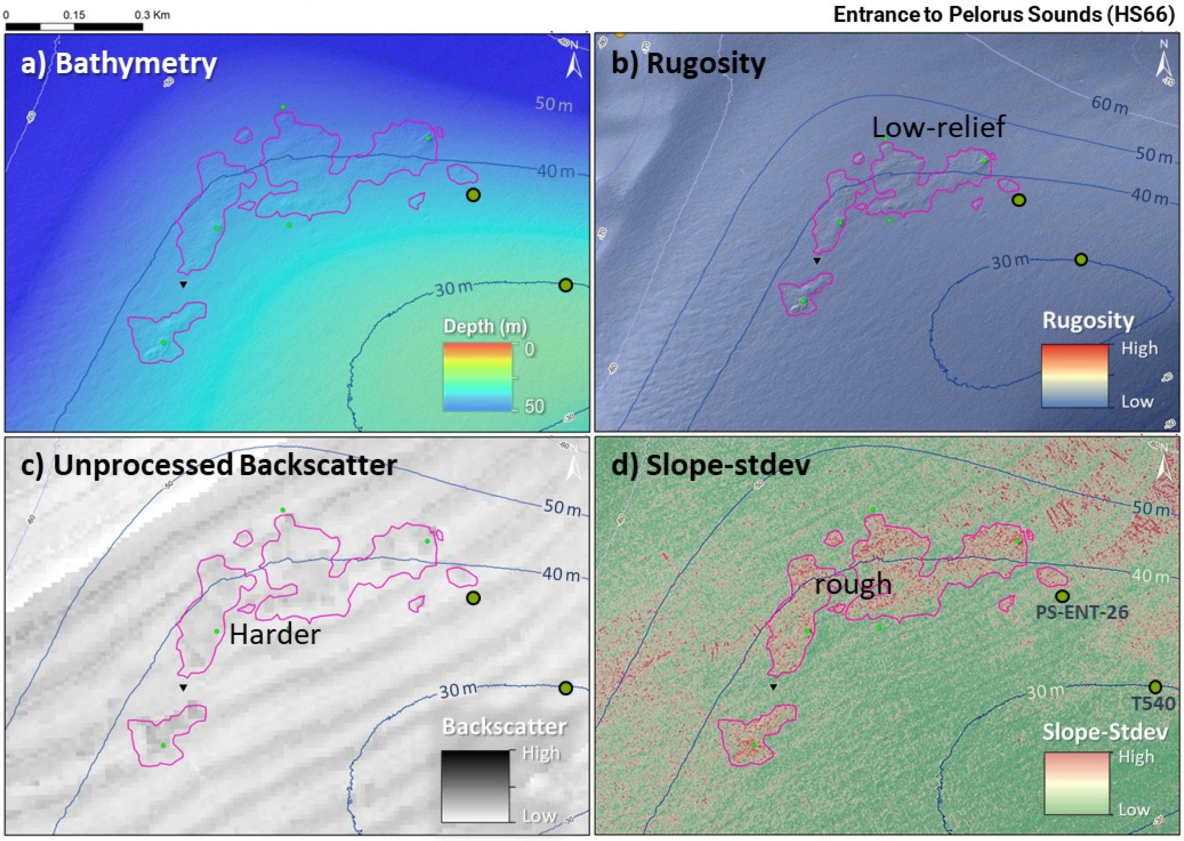


Figure 41. Bryozoan-patch reefs predicted based on MBES layers, located at the entrance to Pelorus Sounds. Pink boundary = predicted bryozoan area. a) HS66 bathymetry (slightly raised bathymetry in depths of 35-45 m); b) Rugosity (all low-relief); Unprocessed backscatter (higher reflectivity = harder bottom); d) Slope-stdev (red=high slope-stdev/rougher seafloor). Ground truthing would be required to verify this prediction. Symbols and locations are described in Figure 40.

4.3.2.2 Backscatter reflectivity & preliminary SRC layers.

Technological advancements in MBES data collection along with revised and ever improving protocols for collection, calibrations and data processing, have, over the last two decades, greatly improved the processing capabilities, and as a result the final mosaiced MBES maps (and their underlying data/or rasters). These have not been minor issues, but MBES researchers have made great strides to improve these outputs (see review in Lamarche et al. 2011, 2011; Lurton et al. 2015). While bathymetry and bathymetry-derived benthic attribute layers (e.g., slope, rugosity, aspect, etc.) and classification algorithms (such as Benthic Terrain Modelling in ArcGIS) are always being fine-tuned and revised to better capture biological-relevant relationships, the outputs from these layers provide excellent detail at ever-refined scales (Brown and Blondel, 2008; Lurton et al. 2015). In contrast, although backscatter has been seen, especially by biologists, to offer some of most intuitively-useful habitat mapping information (i.e., is

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[14] Recommended ground truthing sites (as per Figure 40) were been provided to MDC as of May 2022.

it seafloor substrata hard or soft), the creation of value-consistent backscatter data across the mapped area has been a major hurdle (Rzhanov et al. 2012; Huang et al. 2013; Lurton et al. 2015). However, major effort by MBES acoustic researchers to correct and harmonise these issues (value-consistent rasters and imagery), along with improving the way backscatter data are collected, calibrated and processed has helped to ensure that the fully-processed mosaiced-imagery and associated raster/data provide the end-users with 'fit-for purpose' raster layers (i.e., value-consistent backscatter across the full-scale of the map (Lurton et al. 2015; Neil et al. 2018). In the recent MBES-HS66 surveys a suite of protocols were put in place to ensure that the two MBES surveys followed tight backscatter procedures and protocols. This included using a controlled frequency (300 kHz) and pulse length, and repeatedly re-surveying the same 'calibration-site' through time etc., both within the HS66 survey area (i.e., Waitata Reference/calibration site), but also within the HS51 survey area (i.e., Waikawa Reference site) - to ensure consistency both between survey vessels, but also to ensure accurate calibration between the original MBES-HS51 backscatter data and the newly collected MBES-HS66 backscatter data (Mackay et al. 2020). These MBES-backscatter 'collection and calibration protocols' were all QA/QC by the respective survey teams, and by NIWA who carefully oversaw and subsequently QA/QC'd the backscatter and water column data (Mackay et al. 2020) and reported them both fit-for purpose and was of high quality. Specifically: Mackay et al. (2020) reported that "*Backscatter data from the multibeam echosounders used in HS66 have been analysed only to a level that allowed an assessment of data completeness for quality assurance and readiness for future scientific investigation. These data will need to be fully processed before quantitative analysis can proceed*". Following these QA/QC steps, Orpin et al. (2020) then undertook a secondary classification on the 'preliminarily' backscatter data, by classifying the "raw unprocessed" backscatter data into four Seafloor Reflectivity Classifications (SRC), using the same classification definitions that were trained and verified using the earlier MBES-HS51 data (Neil et al. 2018). However, this secondary classification of the backscatter (i.e., the SRC raster) has not been provided to MDC. However, based on the preliminary evaluations undertaken during this review, this new SRC layer is also presently 'fit for scientific purpose'. This assessment is based on:

i) The HS66 backscatter having been carefully calibrated with the MBIE-HS51;

ii) The fact that the original trained HS51-SRC categories were validated by grain size analyses from the extensive HS51 ground truthing campaign's sediment grab samples, along with video observations from the paired dropcam surveys (as described in Neil et al. 2018);

iii) The very similar geomorphic settings of the Eastern and Western Sounds - whereby inferences from one region would be expected to be relevant to the other region; and

iv) Importantly, that the new CBed-classification align very well and thus validate these SRC categories.

4.3.2.3 Seafloor Reflectivity Classification (SRC) (backscatter raster).

The new CBed ground truthing classifications (as described above) in combination with a seabed reflectivity classification layer would be extremely valuable in helping to predict significant marine habitats and their associated biological diversity, along with other MBES and environmental layers. The geo-rectified image plotted in this review is already extremely useful to aid in the visual assessment of significant sites. A seafloor reflectivity classification 'raster' layer would be considered critical for any quantitative analytical approaches, both for predictive habitat suitability modelling, based on modelled relationships from the Eastern Sounds, and in modelling new HS66-specific organism-environment relationships (see Section 0, below). However, the QA/QC'd backscatter data can be readily reprocessed and a similar Seafloor Reflectivity Classification reapplied to the post-processed backscatter. The advantage of the latter is that MDC need to reprocess the backscatter anyway for direct observational use and to provide seafloor mosaiced backscatter imagery for Pelorus South (which is currently absent: see Figure 4). Predictive modelling approaches

4.3.3 Physical Surrogates (as proxies) for predicting key taxa & habitats

Physical surrogates are where you use one or more physical data/map layers to predict where a species or community will occur. For example, if you have a map layer (e.g., Class-7 of the Benthic Terrain Model) and you know that Sp A is always found in BTM Class-7, then you can use the plot of Class-7 to predict where else you might find Sp A. However, biology is rarely so simple. For example, while 100% of Sp B may be found in boulder habitats, not all boulder habitat will have Sp B. As a result, this correlative relationship can be analytically weak. This is a common issue. In this hypothetical example (loosely based here on benthic octopuses (Anderson 1997)), only those boulder habitats near prey fields (e.g., scallop beds) have Sp B. Consequently, to model and map Sp B you will need a map of both the boulder fields and the location of the scallop beds. Habitat suitability modelling (also referred to as species distribution modelling) is just a multi-variate way of measuring those organism-habitat-environment-relationships, and then using those relationships to predict those key taxa over the larger management-areas of interest.

Species-habitat relationships are generally more complex, and to make things more difficult, often very species-specific (e.g., Anderson and Yoklavich, 2007; Anderson et al. 2009). As niche theory explains, species may use different habitats, and/or different microhabitats within the same broader-scale habitat (Leibold, 1995; Meynard et al. 2007; Boulangeat et al. 2012). For example, in California there are 72 species of benthic rockfish species (genera *Sebastes*), yet each species uses the benthos in different ways (Love et al. 2002; Anderson et al. 2007, 2009; Iampietro et al. 2008). These include using different areas of the reef, different substratum types, or different microhabitats – where over extended reef-mud transition zones, only species occurs on mud but only in mud at the edge of reefs, while another also only occurs at the edge of reefs, but only on rock patches (Anderson et al. 2009). So, in terms of predicting where key taxa are within the Marlborough Sounds, the two key things are: 1) you need is to know something meaningful about the organism-habitat-environment relationships, and 2) those surrogate (or predictor) variables need to be available as spatial ‘raster’ data over the spatial extent of the map or area that you wish to predict across. The qualitative approach is a mental (or theoretical) model used to visually examine and identify those target areas on the map.

4.3.4 Habitat suitability models (eastern Marlborough Sounds)

During the HS51 multibeam mapping programme and the subsequent large-scale ground truthing campaign across the Eastern Sounds, numerous species-habitat-environment relationship were identified (T. J. Anderson, Stewart, et al. 2020). Given the many similarities between the Eastern and Western Sounds, these relationships should provide some excellent insight into where similar notable and significant habitats and communities would be expected to occur in the Western Sounds. As a consequence, both qualitative (visual) and quantitative (analytical) approaches using these relationships should prove fruitful. In addition, those analyses of organism-habitat-environmental relationships already modelled for the Eastern Sounds (Anderson, Anderson et al. 2020; Anderson et al. 2021) can be used to quantitatively predict similar significant sites in the Western Sounds. However, for this to be successful the mapped layers need to be available. The best example of this issue is predictive mapping of *Galeolaria hystrix* mounds.

Anderson et al. (2020b), examined a wide range of physical (MBES raster layers, Neil et al. 2018) environment (benthic currents, Hadfield et al. 2014) and map-derived spatial layers (e.g., distance from reef) to predict the species distribution of *Galeolaria* mounds across the Eastern Sounds (HS51 survey area). These predicted relationships were then used to map the likely (or predicted) abundances and occurrences (using two separate and an ensembled Boosted Regression Tree models) over the entire mapped HS51 survey area (list of predictor variables are shown in Table 6; while full descriptions are provided in Anderson et al. 2020b). In this approach, reserved observational data were held back and then used to test how well this model fit the observations and these remaining (validation) sites. In the

Galeolaria example, the model had good predictive fit, with low uncertainty. These mapped distributions also provided managers with a real hands-on spatial tool that allowed further targeted investigations of these predicted *Galeolaria* zones.

These modelled relationships could now be used to analytically predict the location of new *Galeolaria* mounds sites within the Western Sounds (HS66 survey area). Importantly, however, this would require the same suite of continuous-cover variables (as shown in Table 6) to be available for the entire HS66 survey area. In this situation, the predicted distributions for the HS66 region, could then be validated using the broad-scale tow-video survey observations from the HS66-2020 ground truthing campaign, along with existing or targeted 'new' ground truthing data. These additional data could also subsequently be used to fine-tune the HS models performances for improved precision across the broader Marlborough Sounds management region.

In the *Galeolaria* mound quantitative modelling approach, NIWA's MBES-HS51 Seafloor Reflectivity Classification layer was one of the 10 important predictor-variables needed in the Habitat suitability model. Consequently, this layer, along with % sand would also be required for this approach (at least for this species) to be effective/possible. Given this SRC layer provides critical information on the composition (hard to soft) of the seafloor, it is highly likely that this variable would be critical in most species-models. However, in the interim (while this data layer is being sourced or re-processed), the geo-reference image can be visually interrogated to qualitatively do the same thing.

The advantage of the quantitative modelling approach is that you are letting the computer do the work of finding suitable habitats (here sites supporting significant benthic biodiversity). Although a qualitative approach is a perfectly acceptable interim approach, this becomes more difficult as more complex relationships get modelled, and predicted over more complex visual landscapes. For example, while for some isolated pockets of habitat (such as the bryozoan patch-reef zones) it is easy to interrogate all the layers and manually delineate boundaries, for other more complicated relationships and systems, this can become a very difficult and laborious task, which the computer models can do much more efficiently. In addition, species relationships with their environment are not always linear, but rather often reflect discrete threshold relationships (no sp C until benthic current reach a specific flow rate then lots of sp C occur). So, modelling approaches need to ensure that these relationships are accurately modelled. This may also be easily done by altering the colour-scales of the near-bottom current speed map to investigate changes in habitat reflectivity levels.

Table 6. Predictive environmental variables used in habitat suitability models for significant habitats and species within the eastern Marlborough Sounds (HS51 survey area). Abundance (%cover) was modelled using ensembled Boosted Regression Tree (BRT) methods for three taxa: *Galeolaria hystrix* mounds and bryozoan patch-reefs (Anderson et al. 2020b) and horse mussel (*Atrina*) (Anderson et al. 2021); while (Ribó et al. 2021)) modelled presence/absence distributions of six species, including *Atrina*, green-lipped mussel (*Perna canaliculus*), scallops (*Pecten*), dog cockles (*Dosina zelandica*) and brachiopods (*Calloria inconspicua*), using Maximum entropy (Maxent) models. VRM=Vector Ruggedness Measure (referred to as rugosity). Next steps: green ticks = numeric (raster) layers have been created and are available to MDC; orange 'Most' = available for most of the HS66 area, but doesn't yet include French Pass; underlined grey ticks = no data currently available, but these layers can be quickly created in ArcGIS; red crosses=Data not currently available and requires additional processing and time-related delays.

Environmental variables	Units	Native resolution	Source	*Galeolaria* mounds	Bryozoan patch-reefs	*Atrina*	*Ribó et al 2020*	*Next steps*
Depth	m	2x2 m	MDC	✓	✓	✓	✓	✓
Slope	Degrees	2x2 m	MDC	✓	Not used	✓	✓	✓
Slope standard deviation (slope-stdev)	–	2x2 m	MDC	✓	Not used	✓		✓
Seafloor rugosity (VRM)	–	2x2 m	MDC	✓	✓	✓[15]	✓	✓
Percent sand	%	2x2 m	MDC	✓	Not used	✓		✗
Seafloor reflectivity classification (SRC)	-70 to 10	2x2 m	MDC	✓	✓	✓	✓	✗
Near-bottom current speed	m/s	0.5x0.5 m	MDC	✓	✓	✓	✓	most
Distance to rock	m	2x2 m	MDC	✓	Not used	✓		✓
Distance to headland	m	2x2 m	MDC	✓	Not used	✓		✓
Curvature	–	2x2 m	MDC	Not used	Not used	✓	✓	✓
Bathymetric Position Index (BPI)		-	-				✓	✓
Orientation (° from north)	Degrees	2x2 m	-				✓	✓
Benthic Terrain Classes (geomorphology classes)	–	2x2 m	MDC	Not used	Not used	Not used	✓	✓

However, one ongoing issue associated with a quantitative modelling approach, is the computer power required to model and map high-resolution MBES raster data. Multibeam mapping now generates extremely large datasets. In Marlborough Sounds MBES survey examples, the MBES physical data layers were mapped/generated at a horizontal resolution of 2 m, over an area of 433 km^2 for the eastern Sounds (and 325 km^2 in the Western Sounds), with the former generating 5,549,300,000 depth-data points (Neil et al. 2018), so each time one includes a raster data layer the amount computer power required greatly increases. A good example of this was the modelling undertaken for *Galeolaria* mounds and bryozoan patch-reefs in the HS51 survey area (Anderson, Anderson et al. 2020). To run habitat suitability models across the entire HS51 survey area for > 10 MBES and environmental (predictor) layers were examined (Anderson et al. 2020b), which at 2 m grids, was just too large for the multi-core computers at NIWA to successfully run. Consequently, each physical layer was re-gridded at a horizontal grid size of 8 m. This modelling approach worked very well at predicting *Galeolaria* mounds over both large-scale spatial distributions (scale of the map) and fine-scale alignment with local features (e.g., validated distribution

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[15] Referred to as Vector Ruggedness Measure (described in Neil et al. 2018a,b).

over Perano Shoals). Similarly, while the 8 m grid size was adequate to model the large-scale spatial occurrence of bryozoan patch-reefs across the entire HS51 survey area (i.e., accurately predicted bryozoans across the entrance to QCS), it was not very accurate at finer-scales – as it was not able to delineated the actual boundary locations of these patches. This was because the bryozoan-reefs were very patchy at fine spatial scales (< 8 m), reflecting the occurrence of small mounds of hard bryozoa surrounded by a matrix of mud at scales < 8 m. In this situation, the mean value (per 8 m grid) for both slope-stdev and rugosity (both key variables for delineating patch boundaries) simply evened out (i.e., mean of high and low rugosity patch values, resulted in similar/even intermediate mean values right across the entrance to QCS) and removed those critical threshold boundary relationships that were required to delineate these patchy habitats. This problem was a limitation of computer power, and a trade-off between large-scale generalisation - which was prioritised to determine if there were other locations where bryozoan-patch reef might be present - and fine-scale delineation of these known patches. In this situation, visual delineation of these finer-scale patch-boundaries was much quicker and easier (and cheaper) than re-creating the model for a smaller targeted area (i.e., outer sounds with a finer resolution grid size). However, while computer resources are constantly improving, so too are the resolutions at which multibeam data are being collected. Just in the time between mapping the Eastern and Western Sounds, the horizontal resolution of these maps has improved from 2 m to 1 m (and 0.5 m in some subregions) of the HS66 survey. As a consequence, this is issue will not be going away in the near future. However, wise overview of how species are modelled will be crucial here. For example, in fish-seagrass analyses, a different summary variable of the exact same measured variable will be important for different taxa. For example, for fish1 maximum (or upper quartile 3) may be an excellent explanatory (predictive) variable, while for another species, the variance of the mean may be the better predictor. This indicates how important it is to get the organism-habitat relationship right, before trying to predict that relationship over larger areas.

4.4 Historic assessment of significant habitats and communities

Historical information is often hard to interpret, especially where no formal monitoring has been undertaken. However, as high-resolution mapping becomes more prevalent, other forms of historic data become more interpretable relative to the physical landscape-scale evaluation. Within the HS51 survey area there is a range of historic data and knowledge, that when combined with more recent ground truthing data and overlaid on the MBES-HS66 high-resolution map layers may provide valuable information. This can be used to both help ground truth these maps, and also to help evaluate how these benthic environments may have changed. Below (see Section 4.5) a range of existing benthic surveys, and past knowledge are described that would be valuable to assess in these regards, and that could be sourced and collated (where possible) as part of the habitat mapping and significant marine site planning. Some of these data have been collated as part of this review but there is further collation required. For example, survey sites from the McKnight (1969) survey could be entered for overall completeness of these data (specifically but limited to the area within the HS66 region, as listed in the papers appendix), and that historic surveys be examined and linked to museum specimens where possible/available. These sites can then be aligned with Museum collections, which may then help to provide some important historical knowledge and inference on the community and habitats that were once (and perhaps still are) present at these locations. When new targeted ground truth sampling is undertaken, these historic sites and information may help to best determine where ‘new sites are best allocated.

Jones et al. (2016) reported a total of 21 Local Ecological Knowledge (LEK) polygons depicting 8 biological habitat types within the HS66 survey area, based on interviews with long-time fishers.

LEK polygons were preliminarily evaluated relative to the HS66 MBES physical layers (e.g., the shape and configuration of the seabed relative to these polygons) and other historic and recent ground truthing information to determine if:

i) These habitats still persist, and if so, what condition they might be in;

ii) What ground truthing data exist within or adjacent to these areas; and

iii) Where new targeted ground truthing sites may help provide additional or needed clarification; and

iv) Determine the potential value of these LEK-polygon locations and descriptions in gaining insight into where significant biogenic habitat may still occur, and/or

v) Recent data comparisons exist to evaluate how these communities may have changed.

Preliminary assessment of these LEK polygons when overlaid on the MBES layers (e.g., HS66-Bathymetry: Figure 42 and NIWA's preliminary SRC layer: Figure 43), and examined relative to new CBed-classifications, and all existing data (including both historic and/or recent ground truthing surveys), found repeatedly strong spatial alignment and corroboration with maps and existing data for many of these polygons (Preliminary polygon assessments are provided in Table 7). Each of these LEK-polygons is presented and summarised in Table 7. Three examples are presented in more detail here, to show how these data layers might be evaluated.

4.4.1 Current-swept biogenic community - 'South Passage', French Pass/ Te Aumiti

Three overlapping 'Local Ecological Knowledge' (LEK) polygons were drawn over areas of seafloor in the southern passage, south of French Pass (Jones et al. 2016; Orpin et al. 2020), by long-time local fishers (Jones et al. 2016; see Figure 42, Figure 43 and Table 7). This whole area south of French Pass was reported to have high amounts of corals and sponges (LEK polygon-10), with additional polygons depicting more localised areas dominated by sponges in the southern section of the channel (LEK polygon-13), with an overlapping area denoted as having shell hash (LEK polygon-12). More recent surveys, including HS66 ground truthing sites, and personal observations made during the MBIE-funded 'Bottlenecks juvenile fish-habitat programme', has verified and characterised the southern passage (Figure 44 and Figure 45) as supporting low-lying biogenic structure composed of erect sponges, bryozoans, sparse horse mussels, and screw shells (*pers. obs.*), and also supported juvenile blue cod (Anderson et al. *in prep.*). Species seen in this biogenic zone included, screw shells; erect sponges (e.g., *Chondropsis topsenti, Crella incrustans*, *Ecionemia alata, Callyspongia stellata, Stelletta conulosa, Dactylia varia*), and small-sized patches of the reef-forming bryozoa, *Celleporaria agglutinans* (Tasman Bay coral). In addition, five species of frame-building hard bryozoa have been identified from the southern passage, south of French Pass (location: -40.935, 173.8067, depth 31 m), including: *C. agglutinans, Galeopsis porcellanicus, Cellaria immersa and Arachnopusia unicornis* (e.g., NZOI Site C857). Based on the examination and comparative interrogation of i) MBES layers (e.g., Figure 44a-f; Table 7); ii) the new CBed classification for existing ground truthing sites; and iii) personal observations from several MBIE-2107 sites, a preliminary polygon has been created for this newly delineated current-swept biogenic community'. This low-lying biogenic zone represents a mixed-species assemblage characterised by erect sponges, bryozoans, with horse mussels and screw shells. These, and other associated taxa, are growing in water depths of ~25-32 m across the sediment channel of the southern passage (Figure 45b). NIWA's SRC layer depicts this biogenic-zone as having a moderately level of seafloor reflective, while the slope-std indicates a rough bottom. Ground truthing at distances along this southern passage would be required to verify the northern boundary of the new 'biogenic zone', which presently aligns with a change in depth (depth profile in Figure 45b) and a change in backscatter intensity – loosely based on raw field-processed imagery (Figure 44e).

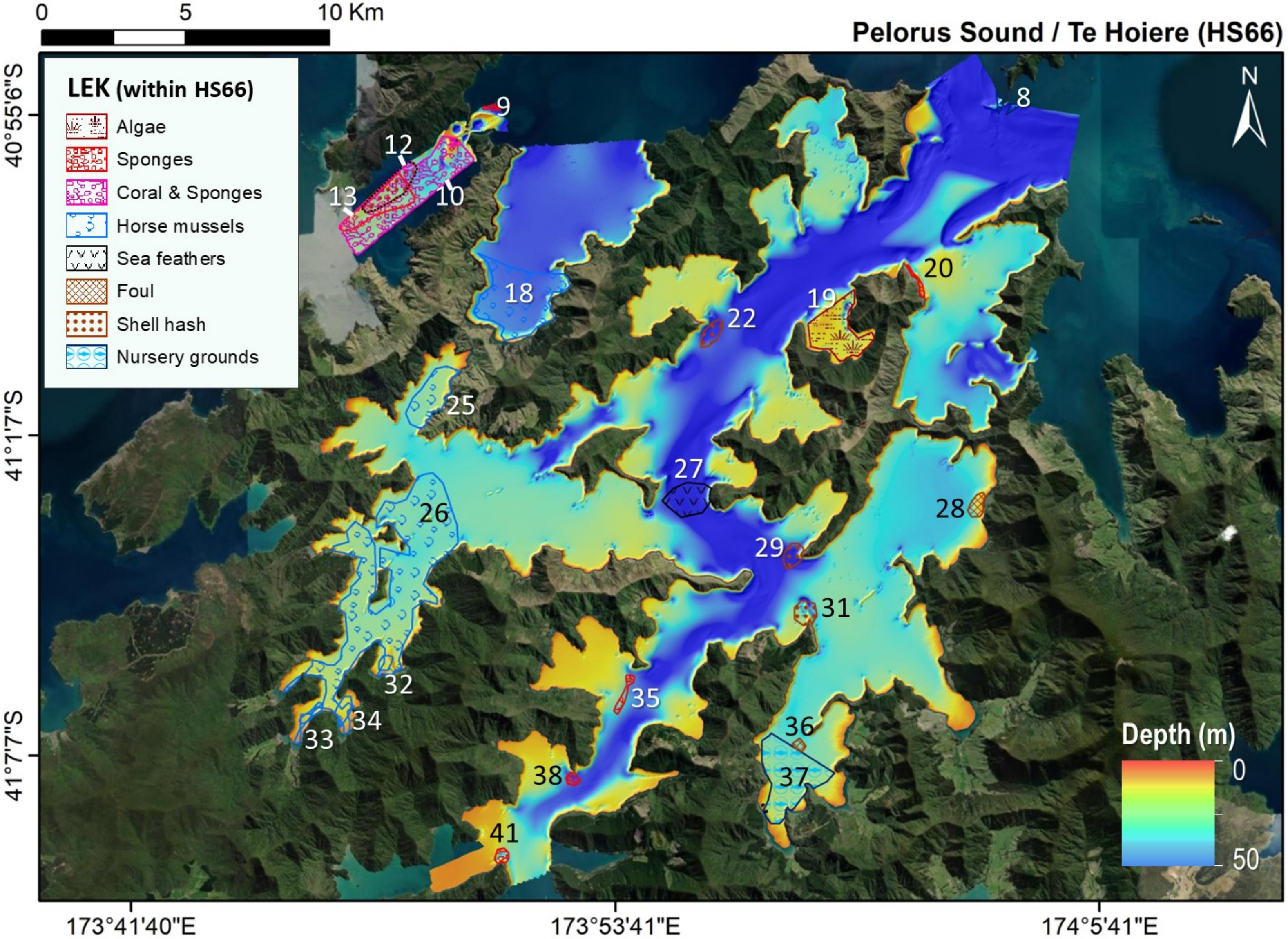

Figure 42. Local Ecological Knowledge (LEK) polygons overlaid on the HS66 bathymetry. LEK polygons are from Jones et al. (2016) (Figure 5 for details).

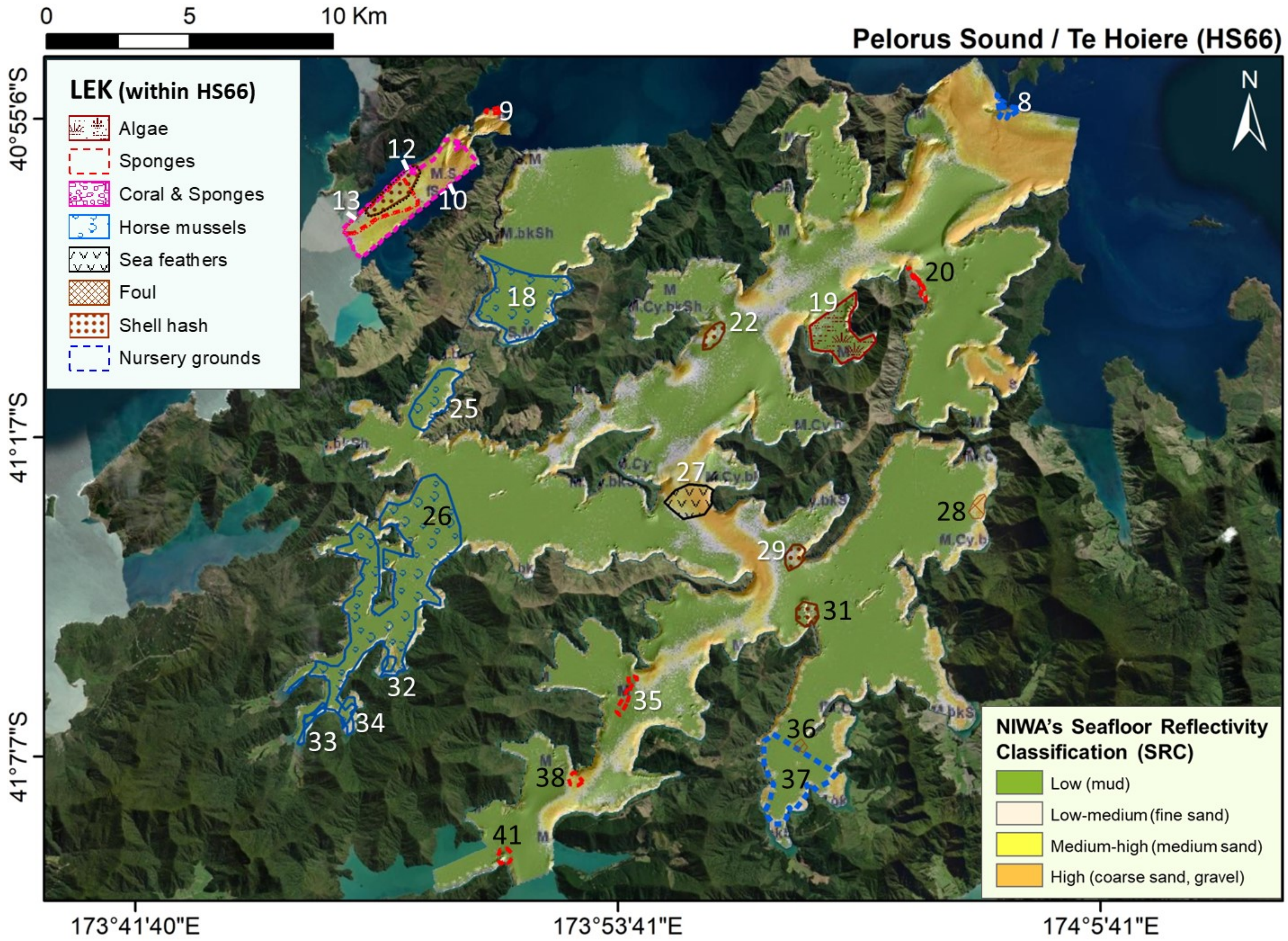

Figure 43. Local Ecological Knowledge (LEK) polygons overlaid on the geo-rectified image of NIWA's preliminary Seafloor Reflectivity Classification (SRC). SRC is drawn from unprocessed and uncalibrated backscatter data (Neil et al. 2018; Orpin et al. 2020); LEK polygons are from Jones et al. (2016) (Figure 5 for details).

Table 7. Local Ecological Knowledge descriptions for polygons described by long-fishers in Jones et al. 2016, located within the HS66 survey area. Original descriptions (columns shaded blue) are based on *Table 19 of* Jones et al. (2016); white columns are based on other sources. HMB=horse mussel beds; SRC layer = NIWA's seafloor reflectivity classification. Green text indicates validation of a LEK habitat/community type; orange text indicates a lack of information to access; and red text indicates the verified loss or negative change in the habitat/community type. Burgundy text in the far-right column indicates additional information is required.

LEK No.	Sub-region	Biogenic habitat description (historic knowledge) from Jones et al. (2016)	Verification	Recent ground truthing verifications of these habitats
9	French Pass (north)	Fisher marked an area to the north of French Pass where soft, yellow, dinner plate sized sponges (8–9 inches/23 cm high) were found, called "spongey cheeses".	**Likely,** not verified	A large number of sites were surveyed over the outer Banks between Rangitoto, Trios and Chetwode Islands, with most sites supporting biogenic communities, characterised by erect sponges, hard and soft bryozoans, horse mussels and a myriad of other associated taxa, so it is likely that these extend down the bank towards French Pass. Would need to be verified, either by viewing existing video or collecting targeted video from in this polygon relative to the HS66 MBES layers.
10	French Pass (south)[16]	The channel south of French Pass was noted as an area of hard ground covered in **sponges and corals**. One fisher noted that this area had been "cleaned out" since it was first fished in the 1960s Coral/sponges (10); shell hash (12), and sponge-dominated (13) See Sections 4.4.1 & 4.4.2	**Yes**, but patchy and not well consolidated.	HS66/MBIE video sites in the south passage channel (south of French Pass) found low lying patchy biogenic structure, supporting mixed sessile invertebrates and diverse associated communities (Anderson *pers. obs.*). Taxa seen incl. screw shells; erect sponges (incl. *C. topsenti, C. incrustans, E. alata, C. stellata, S. conulosa, D. varia*); reef-forming bryozoa (incl. *C. agglutinans* – patchy mostly small); other bryozoa (*Caberea* sp.); *Atrina* (low numbers); small crabs; juv. blue cod; and mobile responders (e.g., sea cucumbers, starfish and brittlestars- *pers. obs.*). Biogenic zone delineated, but some additional verification of boundary-location should be undertaken (see: Figure 45 and Figure 46).
12				
13				
18	Admiralty Bay	**Horse mussel beds**, on sand / mud substrate; Beds may no longer be extensive	**No evidence of HMB's** Likely lost	Limited ground truthing sites. DSIR site (T597, 1983) collected dead horse mussel shells, but no live mussels. HS66 dropcam sites [AB14, 2019] within the central/deeper bay reported bioturbated muddy sediments (No info on Horse mussels). Some horse mussels (sparse) seen in shallower depths in muddy sediments (with biofilm) at the south end of the bay (pers. obs.), around the mussel farms.
8	North Pelorus	**Blue cod nursery grounds** (Chetwode Islands)	**Yes**	**Blue cod nursery grounds** were verified in 2017 for areas around Chetwode Islands (Anderson *in prep.*; Anderson *pers. obs.*); Duffy et al. 1989-90 also surveyed the southern end of Chetwode Islands [Site R254][17].
19	North Pelorus	**Red algae and scallops**	**Yes**	Fishery bycatch confirms **algae (and scallops)** occur across Ketu Bay.

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[16] It is unclear from the published map which numbers (i.e., 10-14) go with which polygons/demarked habitats.

[17] Although no information is available to determine if these dives found juv. blue cod, as dives were undertaken over summer, not in late autumn when juv. blue cod are most common.

LEK No.	Sub-region	Biogenic habitat description (historic knowledge) from Jones et al. (2016)	Verification	Recent ground truthing verifications of these habitats
				HS66/MBES sites had bioturbated mud with some algae (e.g., *Haraldiophyllum crispatum, Schizoseris* sp.) & algae-mats/thick biofilm, scallops and starfish. Patches of chaetopterids tubeworms were also present within the Bay.
20	North Pelorus	**Sponges** (nearshore polygon over reef)	**Yes**	HS66-2020 NIWA [Sites WB-PT-TRANS^{Reef}, WB-PT-TRANS^{Base}, WB-TRANS] reported "**large sponges**" on reefs directly adjacent to LEK-zone; Duffy et al. 1989-90 also surveyed inside [Site R169] and outside [R170] this LEK polygon.
22	South Pelorus	Small areas of **shell hash**	**Yes** MBES	**Correlates well with NIWA's SRC layer** that depict higher reflective sediments here, as well as bathymetry depicting a slightly deeper hole (~15 m deeper than surrounding seafloor), where shell debris may accumulate. However, shell-debris may be thickly embedded in the sediment matrix (based on the many grab sample photos within the HS66 survey area, and the muddy-shell sediment collected during the MBIE-2017 Beam trawl survey, rather than shells accumulating and armouring the seafloor, as commonly recorded in the outer sounds zones of high reflectivity shell-debris areas. However, no ground truthing or historic sites exist to validate/characterise this site, but would consider this a lower priority site to ground truth.
25	South Pelorus	**Horse mussel beds**, on sand / mud substrate; Beds may no longer be extensive	**Unknown** Likely lost	Targeted ground truthing required to assess this large zone
26	South Pelorus	**Horse mussel beds**, on sand / mud substrate; Beds may no longer be extensive	**Unknown** Likely lost	Targeted ground truthing required to assess this large zone
27	South Pelorus	**Sea feathers and starfish** (*Coscinasterias muricata*)	**No evidence of sea feathers** Likely lost	HS66 dropcam site (TR-111) found patches of shelly muds with sponges and hermit crab; while NIWA's SRC layer illustrates higher reflectivity in the channel, indicative of shell & biogenic structure. Targeted ground truthing required to assess this zone. Recommend existing NIWA HS66 video (i.e., sites TR-111 and nearby CH-DML-56) be examined.
28	South Pelorus	**Foul ground** (**untrawlable** areas) **Nearby sites, with similar seafloor types, covered in exotic brown alga**	**Unknown**, likely scallop shell debris with algae.	No ground truthing sites within this LEK polygon, but SRC layer shows high reflectivity in a 600 m wide band alongshore. Nearby ground truthing sites (in same high reflectivity class) has muds covered in large shells (mostly scallops); **benthos also covered in dense meadow of the brown algae 'gold socks' (*Asperococcus bullosus*) and *Colpomenia*.**
29	South Pelorus	Small areas of **shell hash**	**Yes** MBES & verified	This polygon covers part of the headland-reef and slope off Whakamawahi Pt than extends ~600 m offshore, as well as predicted shell debris around the base of the slope extending ~400 m further offshore towards the

LEK No.	Sub-region	Biogenic habitat description (historic knowledge) from Jones et al. (2016)	Verification	Recent ground truthing verifications of these habitats
				centre of the channel. Nearby HS66-2020 NIWA Sites [TR_112 56 m] "**Mud, burrows, patches of scallop shells with a few sponges**" & [CB_REEF] "**patchy shell on mud with starfish**" these sites occur in the same high SRC area.
31	South Pelorus	Small areas of **shell hash**[1] [1]Likely/poss. the fishers new this extensive submerged reef was there (but trying to fish over it), and therefore were likely referring to the shell debris around the base of this bank, not the bank itself. However, both are likely important biogenic habitats.	**Yes**, but also rocky-ridge	*Centre of this polygon is an…* **Extensive submerged rocky ridge** with 'large sponges and fish on its upper bank' and '*Tucetona laticostata'* shell debris armouring upper slope' (MBES-2017, CB17-PSC19, *pers. obs.*). Prior to the MBES maps, this bank appeared as "*rising ground out in the middle of nowhere*" (MBES-2017, CB17-PSC19, *pers. obs.*); HS66 bathymetry revealed an extensive submerged rocky ridge 600 long x 150 m wide extending NNW off Opani-aputa Point. SRC layer, also depicts high reflectivity around this feature that spatial with dense *Tucetona*-armoured shell debris seen on the upper banks (*pers. obs.*). SRC & Slope-Stdev layers also infers high reflectivity and roughness, respectively, in holes at the base of this ridge (~poss. shell accumulation in holes). MBIE site [CB17-PSC19 ~19 m) videos the edge of reef c. ~450 m NNE from shore (where tow-cam became tangled on reef); No ground truthing sites exist around the base. **Targeted ground truthing recommended.**
32	South Pelorus	**Horse mussel beds**, on sand / mud substrate; Beds may no longer be extensive	**Unknown** Likely lost	Targeted ground truthing required to assess this large zone
33	South Pelorus	**Horse mussel beds**, on sand / mud substrate; Beds may no longer be extensive	**Unknown** Likely lost	Targeted ground truthing required to assess this large zone
34	South Pelorus	**Horse mussel beds**, on sand / mud substrate; Beds may no longer be extensive	**Unknown** Likely lost	Targeted ground truthing required to assess this large zone
36	South Pelorus	**Rock pinnacles** (untrawlable areas)	**Yes** small raised bank nearby, so likely (misaligned)	Polygon is over homogeneous mud, but description & size aligns with a (<~300 m away) small raised bank (228 long x 66 m wide, & 5 in height) See (described and mapped in Section 4.3.1.1: Figure 33). This nearby submerged bank is referred to here as Deep-Reef 2, with some rock outcropping. HS66-2020 NIWA site [CB-87, 26 m] reports mud with lots of scallop shells & few live scallops.
37	South Pelorus	**Snapper nursery grounds** (See Section 4.4.3)	**Unknown** Likely lost	**No juvenile snapper seen or captured** in MBIE-2017 Beam-trawl site (BT17-PS62), but some issues with retrieving this catch (*pers. obs.*). Beam trawl catches from all sites within Crail Bay (Snapper nursery ground LEK-37) were too heavy to retrieve so the catch was partially released/compromised, with no snapper caught (*pers. obs.*). Juv. snapper are cryptic and use a range of biogenic nursery habitats, especially seagrass

LEK No.	Sub-region	Biogenic habitat description (historic knowledge) from Jones et al. (2016)	Verification	Recent ground truthing verifications of these habitats
				meadows, horse mussel beds, and other biogenic structure (Morrison et al. 2014; Anderson et al. 2019). Dense *Atrina* beds have been reported from several sites within the LEK-37 polygon zone.
35 38	Popoure Reach	Multiple areas within Popoure Reach where **“sponge material”** was found. This was an area targeted for **scallops**	**Yes HS66-2020**	HS66-2020 site [PR-70, 50 m] reports “***Scallops and sponges***” LEK-38 is delineated within an area where NIWA’s SRC distinguishes high backscatter reflectivity (Figure 43) , where HS66-2020 Sites identified notable amount of shell debris (Figure 23 & Figure 24) that support sponges and *Atrina* (Figure 25b). E.G., HS66-2020 site [PR-69, 50 m] described shelly-muds with “***sponges, scallops and horse mussels***”.

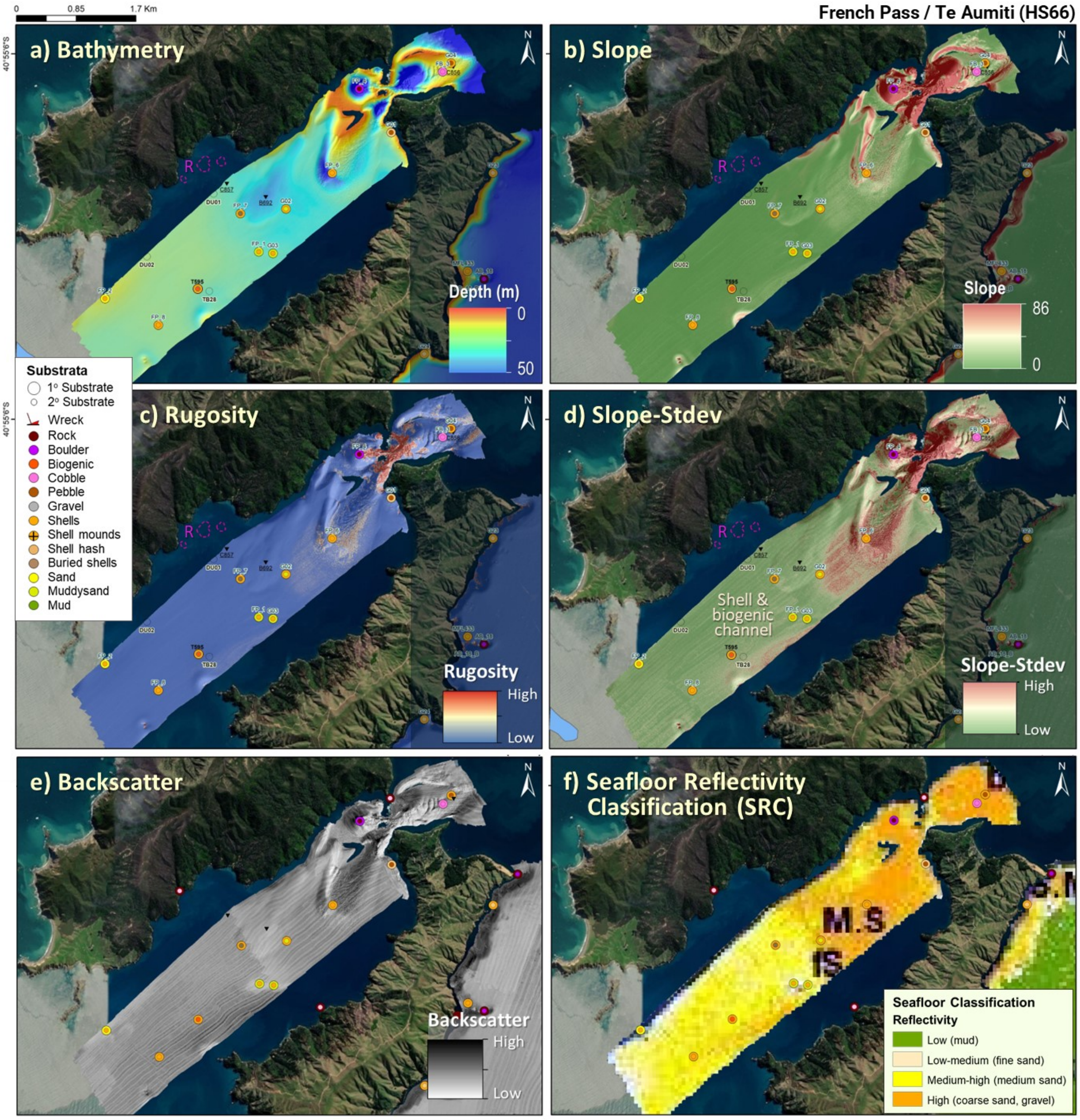

Figure 44. French Pass, example of map layers and ground truthing data available. a) HS66 Bathymetry; b) Slope, red denoting high slope (slope angle of ~6°) within the throat of the Pass; c) Rugosity, red denoting areas of high rugosity; d) Standard deviation of the slope (Slope-stdev), red denoting area of rough seafloor (indicative of low-lying hard debris; e) IXblue's preliminary backscatter layer, here whiter areas depict harder more reflective seafloor surfaces (e.g., rocky reefs, shell-debris fields, and coarse sands and gravels); and, f) Geo-rectified image of NIWA's Seafloor Reflectivity Classification, drawn from unprocessed and uncalibrated backscatter data (*refer to* Figure 5 *captions for more details*).

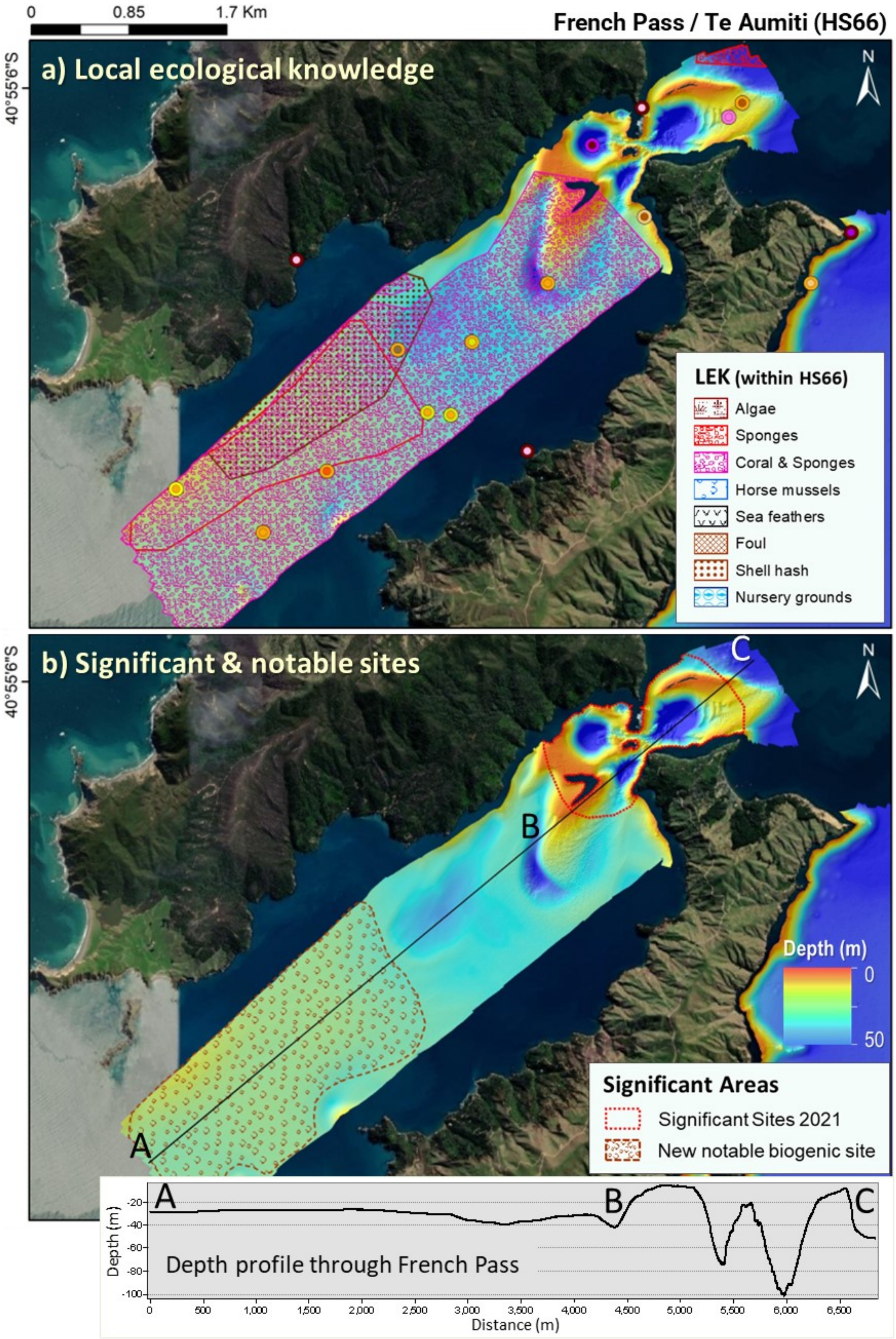

Figure 45. French Pass: Notable and Significant sites, overlaid on HS66 bathymetry. Historic Local Ecological knowledge (LEK) polygons, drawn by long-time local fishers - showing areas of sponges, coral (*cf.* bryozoans) and sponges, and shell debris (redrawn from Jones et al. 2016); b) Significant and notable sites: including a newly-delineated polygon of biogenic habitat (brown patchy polygon) as verified from recent ground truthing (HS66 descriptions; MBES-2017, T. Anderson, *pers. obs*.). Insert showing the depth profile through French Pass, with depths of c. 100 m within the whirl holes in the 'throat' of French Pass (between B and C).

4.4.2 Current-swept debris-field - Immediately south of French Pass

LEK-polygon 10 representing an extensive areas of biogenic habitat characterised by 'corals and sponges' was drawn around the entire south passage, from the southern 'throat' of French Pass to the adjoining Tasman Bay (Jones et al. 2016; see Figure 42, Figure 43 and Table 7). Qualitative (visual) interrogation of the various MBES layers in association with known ground truthing (Figure 44, Figure 45 and Figure 46) was used to evaluate this area. Rugosity overlaid of seafloor roughness (slope-stdev) in association with the bathymetry and backscatter (field-mosaic and NIWA's SRC) layers identified a clear separation between two discernible seafloor features (Figure 44, Figure 45 and Figure 46). These two areas are the already reported 'current-swept biogenic zone in the southern passage' and a more discrete debris-field immediately south of the 'throat' of French Pass (Figure 46 – especially visible in image-a). Based on this combination of information a preliminary boundary around this second biogenic-zone was created, here termed a "current-swept debris-field" immediately south of French Pass. The multibeam bathymetry here shows the shape of a raised tongue-like bedform immediately south of French Pass, formed by what Stevens et al. (2008) described as a tidal jet-current being forced through the raised throat' of French Pass Figure 46). Rugosity overlaid on seafloor roughness provides a clear boundary zone for this debris-field.

Ground truthing video footage (HS66-2020, Site FP-6) identified the seafloor here is covered in layers of whole-shell-debris that 'armours' the seafloor, with sponges, screw shells and blue cod; while grab samples (HS66-2020, Sites FP-6 and G02) collected agglutinated shell debris (Figure 46a; Table 7; full descriptions provided in Orpin et al. 2020) - indicating that sessile invertebrates species (such as sponges, hard bryozoans, hydroids and ascidians) that colonise these shells, can over time bind and semi-consolidate this shell debris (Dewas and O'Shea 2012; Beaumont et al. 2015; Anderson et al. 2019; T. J. Anderson, Stewart, et al. 2020). As only two ground truthing sites exist within this zone, further ground truthing would be required to verify these boundaries, and characterise any within-habitat 'community' variability that it supports. It is unclear, without viewing the dropcam footage collected during the HS66 ground truthing survey, what taxonomic and community differences exist between these two habitats. However, the collation and examination of specimen identifications from museum collections (black triangles in these figures) along with examination of the HS66 ground truthing imagery would be expected to provide more insight into these habitats and their communities.

There may also be spatial patterns in community structure driven by natural but regular disturbance. For example, the power of the tidal currents passing through this narrow passage may also cause some level of frequent spatial-explicit disturbance where the turbulent force of the tidal jets racing through French Pass, might move loose uncemented shells. Based on the high current flow relative to the depth profile through French Pass (Figure 47), one might expect that the southern slope of this raised feature would accumulate shell debris, have high current flow (suitable for biodiverse communities), but be slightly more protected from turbulent flow (that might regularly disturb and move loose shell debris), than the NE side of this feature (Figure 46a,c). NIWA's Seafloor Reflectivity Classification (SRC) across much of this subregion indicates moderate-to-high backscatter reflectivity (Figure 46b), however, it also indicates a transitional band of lower reflectivity sands (reported to support sandy-muds with bioturbation and starfish based on ground truthing: Orpin et al. 2020), that separate the southern biogenic zone from this shell-debris field

Based on these observations and qualitative evaluations, it appears that the original LEK-polygon 10, was correct in its' spatial extent, but current MBES layers would indicate that this may have simply represented the combination of these two slightly different and spatial separated biogenic zones. It appears that both these areas support significant biogenic habitat (dominated by sponges and frame-building hard bryozoans, with significant associated biodiversity), although from fishers' historic accounts the abundance and density of these biogenic taxa (within the entire channel), may

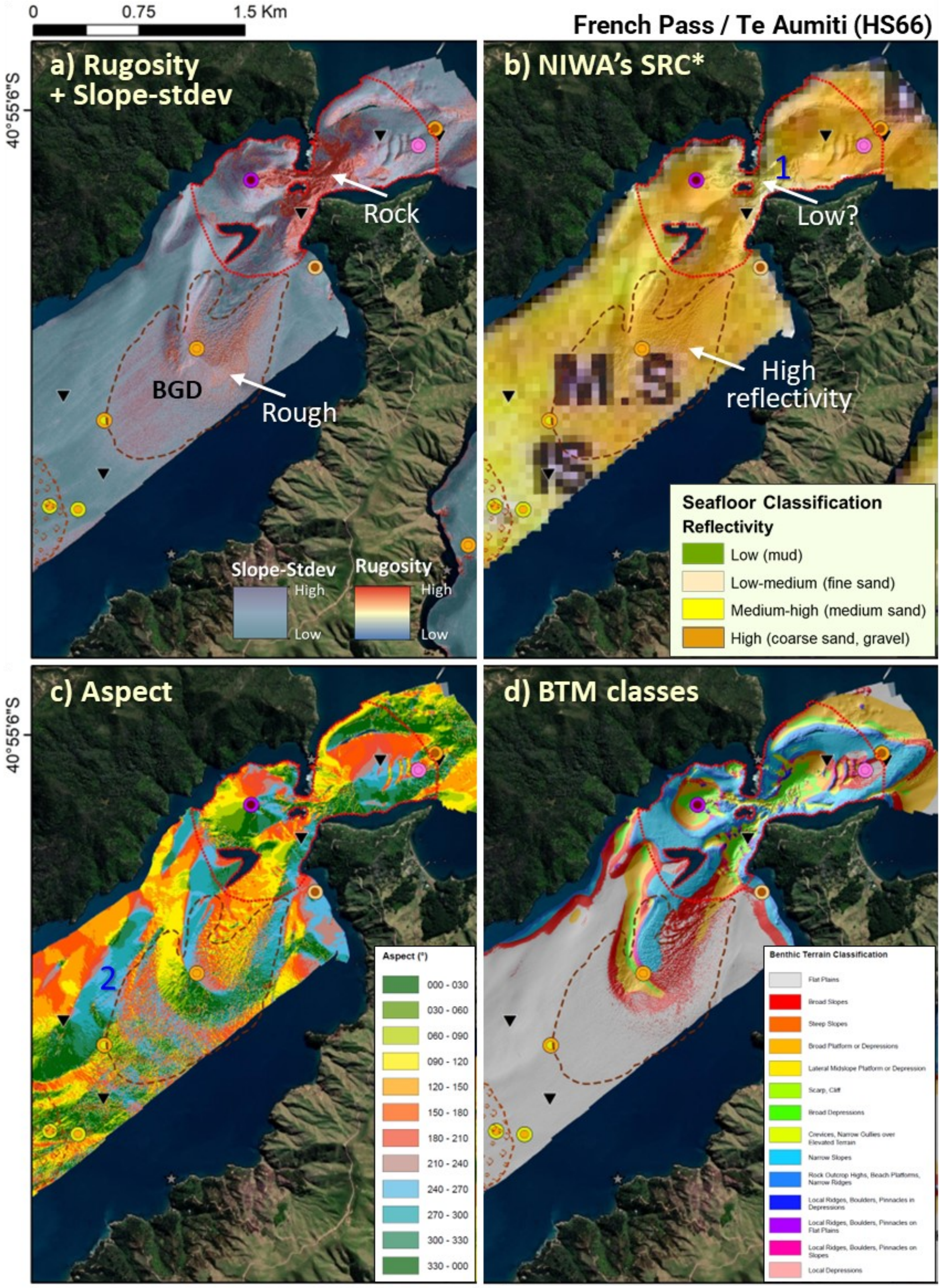

Figure 46. Newly-delineated 'biogenic debris (BGD) field', south-entrance to French Pass, example of map layers and ground truthing data available. a) Slope-stdev overlaid on rugosity, red denoting high slope (slope angle of ~6°) within the throat of the Pass; b) NIWA's preliminary Seafloor Reflectivity Classification (SRC); c) Aspect, (north at 0° =green; east at 90°=yellow; and west at 270°=blue; and south at 180°=red); d) Benthic Terrain Classifications, showing the different geomorphic classes (created by NIWA using ArcGIS Benthic Terrain Modeller). See Coloured symbols.

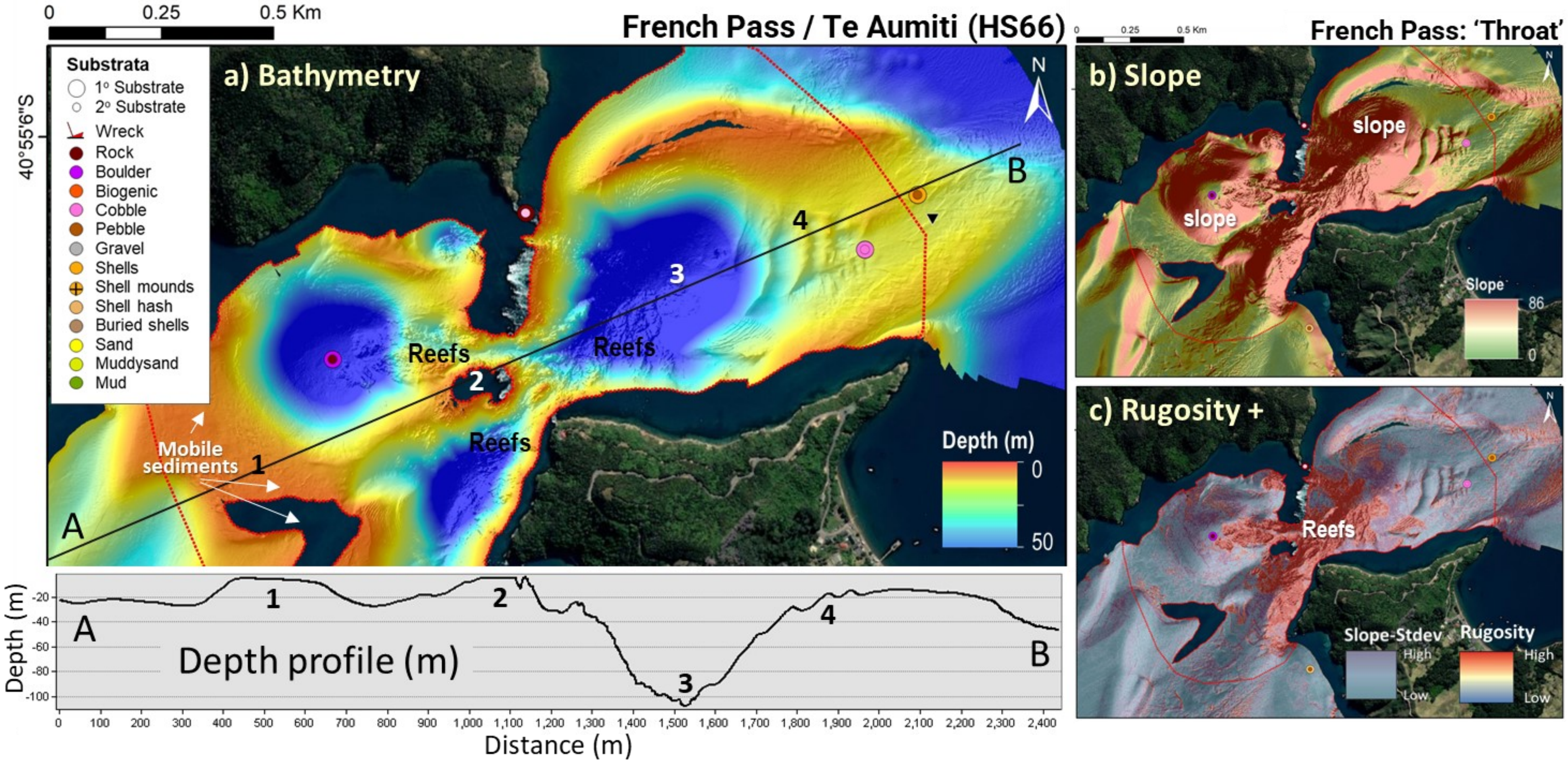

Figure 47. French Pass bathymetry, slope and rugosity, zoomed-in on the 'throat' of the passage (HS66 survey), overlaid on hillshade relief. a) bathymetry, with insert showing the depth profile through French Pass with depths of c. 100 m within the NE whirl holes [3]; b) slope; and c) rugosity over slope-stdev. Red-dotted poly-line depicts the boundary of the French Pass Significant Sites 2.16 (Davidson et al. 2022). Mobile sediments depicted by the arrows are based on those presented in (IXblue 2020).

have been greatly reduced over time due to benthic fishing disturbances (as described in Jones et al. 2016). It is therefore unlikely that these significant habitat and communities are in a pristine state, having been fished by benthic trawlers who collected and delineated these areas as having collected these sponges and hard coral/bryozoans.

Orpin et al. (2020) also reported cockles, but it is not clear if these refer to the large robust dog cockles (*Tucetona laticostata*), or some other species. If *Tucetona* is the dominant shell-material accumulating on the seafloor in this area, then, given the strong currents, we might expect to find a similar suite of encrusting and sessile invertebrate species to those found encrusting whole *T. laticostata* shells out in the Rangitoto passage (Davidson et al. 2010; MBES-2017 surveys, *pers. obs.*), and, within similar current-swept shell-debris field in Queen Charlotte Sounds (Pickersgill and Patton Passages: Anderson et al. 2020c).

4.4.3 Snapper nursery areas - Wet Inlet/Crail Bay (LEK polygon No. 37).

Juvenile snapper are known to be associated with a range of coastal biogenic habitats, including seagrass meadows, horse mussel beds, and other biogenic structure (Morrison et al. 2014; Anderson et al. 2019), as well as muddy areas bioturbated with largeish holes (*pers. obs.* during the MBIE-funded 2018 Northland and the Hauraki Gulf Bottleneck' surveys; Morrison et al. *in prep.,* MBIE *unpublished data*), although it is unclear if juvenile snapper use these holes as a form of refugia. Newly settled snapper can also be very cryptic and therefore hard for non-trained observers to detect and identify (M. Francis, *pers. comms.*), so snapper nursery areas, and the habitats that support them have not been well known, with much of what we known about these nursery habitats only recently discovered (Morrison et al. *in prep.,* MBIE *unpublished data*). Although juvenile snapper are known to have been more common within the upper reaches of the Pelorus Sounds in the past, very few juvenile snapper were collected during the MBIE-2017 juvenile fish-habitat surveys, and these were restricted to the upper reaches of inner Pelorus Sounds Inlets (*pers. obs.*) outside of the HS66 survey area.

During the MBIE-2017 Bottlenecks fish-habitat survey, a total of eight beam trawl sites were surveyed within Crail Bay (2 sites); nearby Clova Bay (2 sites); the outer bay-area (2 sites), and within Beatrix Bay (2 sites) (Figure 8). Most of these tows were hindered by (rope entanglement of farm debris, Clova Bay; or nets becoming overburdened with mud and mudworms, Crail Bay), with nets needing to be partially-tipped (from the front) to get them back safely onboard the vessel (pers. obs.). However, large amounts of catch were still landed, but no juvenile snapper were collected: *pers. obs.*). Consequently, it is unclear whether this reflects the partial-tipping of the sample (although other small cryptic fish and small infauna were collected), or whether juvenile snapper were simply not present. One single MBIE-2017 beam-trawl site (BT17-PS62, 28 m) was surveyed within the historical Crail-Bay Snapper Nursery Grounds (Figure 8; Figure 48). This site was characterised by a similar habitat and community type to that described in McKnight and Grange (1991a) for a nearby dredge site that was surveyed 26 years earlier (i.e., DSIR-1983 Dredge site T563, 29 m depth, Figure 10 and Figure 48). McKnight and Grange (1991a) described this site as having mud with infaunal brittlestars (*Amphiura rosea* and *A. correcta*), heart urchins (*Echinocardium cordatum*) and soft sediment holothurians (*P. longidentis* and *Rynkatorpa uncinata*), along with dead *Atrina* shells[18]. In addition, the MBIE-2017 survey also collected large volumes of mud-covered tubeworms (referred to here as mudworms) along with dozens of scallops (*pers. obs.*). The presence of this large volumes of mudworms, which in combination with the mud that this 'matrix-of-worms' trap, resulted in considerable drag during beam trawl retrievals (making it difficult and unsafe to retrieve), and was the primary reason that incomplete sample retrieval occurred at these sites (*pers. obs.*). However, as mudworm tubes break and disintegrated by the time they are brought up on the deck (even given our very fine nets) it is unlikely that this habitat-forming species would be retained in the DSIR-1983 dredge samples. As a result of this different gear catchability, it is unclear (and possibly unknowable) whether these

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[18] A full species list is provided in the Appendix of McKnight and Grange, 1991a

mudworms have always been a dominant component of these infaunal mud communities, or whether the presence and/or dominance of this species is only recent.

During the DSIR-1983 dredge and diver surveys, researchers discovered a horse mussel bed in Wet inlet, Crail Bay - that supported one of the two densest *Atrina* beds ever reported from the Marlborough Sounds (Hay, 1990; dive sites denoted by light-blue coloured diamonds in Figure 48). Hay (1990) reported that the seafloor at these sites were totally dominated by *Atrina*, with densities of 7-13 *Atrina* per m^2, but that horse mussel condition within this dense bed was usually poor, where individuals had brittle shells (easily crush in a diver's hand) and bed mortality was high. Stead (1971a) also reported collecting commercial quantities of *Atrina* from two dredge sites located within the LEK delineated 'Snapper groundfish nursery' within Crail Bay (LEK polygon No. 37; sites are denoted by bold blue ticks in Figure 48). This indicates that horse mussels were once present in relatively high densities both and around the edges of this historic nursery zone, and given their distribution and abundance in other embayment's (e.g*., Figure 3-3 of* Anderson et al. 2021), may have extended over larger sections of this bay, and if so, would have likely provided an important biogenic nursery habitat for juvenile snapper.

Site specific recommendations:

1. Examine the recently collected HS66 video footage from the two sites within this LEK delineated Crail Bay 'Snapper Nursery Grounds' to determine if there is any evidence of juv. snapper in these videoed sites.
2. Assess what other benthic video data is available within this LEK polygon, and assess the value of these data determining changes in habitat quality and nursery value.
3. Speak with/interview Cameron Hay regarding any other information regarding the spatial extent of horse mussel beds within Crail Bay; and, confirm the location of their high-density *Atrina* bed. This information may help determine how extensive horse mussel beds were within this area.
4. If horse mussel restoration or experimental studies are to be undertaken in the future, this past nursery area should be included as a priority site.

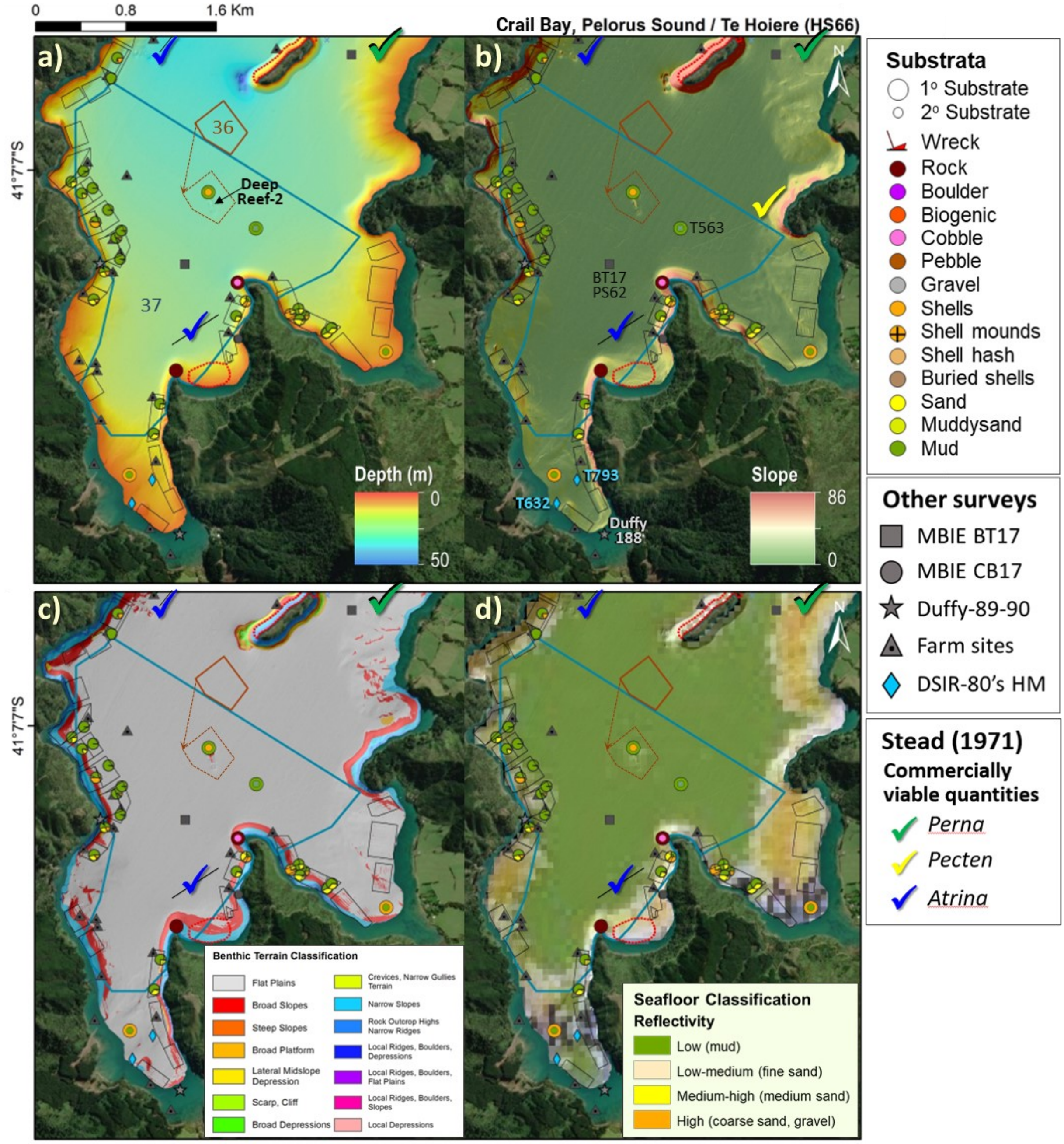

Figure 48. Crail Bay ground truthing data (HS66 collected by NIWA, iXblue and DML) overlaid on the HS66 MBES layers: a) Bathymetry, b) Slope, c) Benthic Terrain Classifications, and d) NIWA's Seafloor Reflectivity Classification (SRC). Here, brown and blue boundaries for LEK polygons 36 (foul ground) and 37, (snapper nursery grounds) respectively (Jones et al. 2016) are shown in (a); Dotted brown polygon – depicts the moved position of LEK polygon 36 likely located around the raised bank/ridge (referred herein as Deep-reef-2, shown in Figure 33). HS66 sites represent sediment grab and/or dropcam sites, with primary (large circles) and secondary (smaller inner circles) substratum type characterised (by colour as per legend) based on information presented in Appendix A-C in Orpin et al. (2020); coloured pie charts are % grain size from inside and outside farm sites; while other survey sites are indicated by grey symbols (as per legend); blue diamond's = DSIR Horse mussel SCUBA sites. The SRC layer is a geo-rectified image of NIWA's preliminary SRC (*see captions in* Figure 5; with methods outlined in Neil et al. 2018 and Orpin et al. 2020); red dotted lines are ESMS boundaries; black rectangles = farm sites.

4.5 Collation of other datasets (based on site metadata)

Collation of historical and recent benthic survey information and museum specimen records, is an important step in ground truthing MBES maps. However, currently there is **no single database** that houses the locations of sites surveyed through time within the Marlborough sounds, or nationally. This is currently an important gap that should be filled, so that this valuable local knowledge is not lost. This report presents the location of sites and available information within the scope of this review (e.g., Table 8 *and maps presented in* Section 3.2), but further effort is required to gather the remaining knowledge. As shown in Table 8 the metadata for these existing benthic surveys, alone, both historic and recent, provide a wealth of data points (n= 1163 data sites) that would likely provide valuable ground truthing information. As such there is a strong need for a desktop study requesting, collating and assessing these data. Data should be plotted in ArcGIS and visually interrogated against the MBES map layers and other ground truthing information, to examine its value in documenting and predicting benthic marine habitats and communities within the HS66 survey area.

For data requests, a two-step approach is recommended: Step one would be to simply send out a suite of requests and collate all datasets that get provided. However, while some of these data should (theoretically) be freely available, some routine staffing-expenses may be incurred, other datasets may incur additional costs depending on the individual agency, institute or private consulting costs. It is important to note that there are a significant number of metadata sites known (>1000) for the HS66 survey area (Table 8). The second would be to examine and prioritise which ground truthing datasets, and/or subsets of sites are most needed. Further examination to define priority sites would be required as part of this second step. A preliminary assessment would be expected to include (but not necessarily limited to) known ground truthing sites that:

1) Occur over complex MBES areas, particularly in areas currently devoid of any other ground truthing information
2) Occur within (or near) historic LEK boundaries, so as to help evaluate/verify the presence of these significant biogenic habitats, as either having occurred in the past (historic records) and whether they still exist (based on more recent surveys (>2010).
3) Occur in the vicinity of historical benthic survey sites, such as any of Estcourt (1967) or DSIR 1980’s survey sites (McKnight et al. 1991a),
4) Occur in areas where there is a predicted likelihood of significant habitats and communities occurring based on extrapolation from other ground truthing sites relative to patterns in the MBES layers.
5) All fishery bycatch sites should be considered high priority requests, but those in and around the main Te Hoiere/ Pelorus Sound channel would be most important - as these data would likely may provide vital insight into the types of fauna and flora that are/were associated with the high vs low reflectivity zones along this main Pelorus Sounds/ Te Hoiere channel.

These site-selection assessments can already be undertaken through visual interrogation of the MBES layers relative to other available ground truthing data. However, as these relationships become visually validated and are identified as important organism-habitat-environment correlates, then a more analytic approach would be recommended to generate modelled predictions of habitat types, community structure and species distributions (e.g., Iampietro et al. 2008; Anderson et al. 2009, 2020b, 2020a, 2021; Ribó et al. 2021).

Table 8. Metadata sources with habitat and/or biological data known for the HS66 survey area.

No. of sites	Metadata Source	Habitat	Biology
356[1]	Marine Farms (SmartMaps) Metadata (<2010 provide by R. Davidson)	✓	✓?[2]
> 200	Morrisey et al. (2015) benthic survey sites	✓	✓
> 200	Brown et al. (2016) benthic survey sites	✓	✓
125	Cawthron Benthic survey sites (> 2010)	✓	✓
102	*Mycale* sponge-discover sites – *targeted reef-sites* (Page & Handley *unpublished data*)	✓	✓
89	Duffy et al. (*unpublished data*) < 20 m depth	✓	✓
72	MBES-2017 'Bottlenecks' surveys (Anderson et al. 2019)	✓	✓
19	Cole et al. (2001)[3]	✓	✓?[2]
> 74[4]	Museum specimen collections (> 1000 specimens)	*Inferences from biology*	✓
? lots	Fisheries bycatch data sites	*Inferences from biology*	✓
1163[5]	Total Metadata sites (as identified in this review)	✓	✓?[2]
	Total sites with some habitat data	✓	-

[1] May not be complete, and may overlap with some grain size data sites already presented in this review – but further collation and removal of duplicates would be required.
[2] Likely to be difference in the survey methods, gear and data types – would require collation and examination.
[3] More sites surveyed for other projects but metadata was not available for this review.
[4] A full assessment would be required here to collate and evaluate these data, and remove duplicates and non-benthic taxa (etc.), before determining how many sites exist within the HS66 survey area.
[5] Here the total records do not include the Museum specimen records, as these most likely reflect collections from surveys documented in this table)

4.5.1 Museum/specimen records

Collation of historical and recent museum species records are a valuable resource when mapped spatially over the MBES layers. They can determine what species occur at a site, which can now be examined relative to the underlying MBES layers. Where species that are indicative of a habitat type (e.g., *Amphiura*-dominated communities) or where multiple species from the same site have been curated (e.g., sponges, hydroids, and bryozoans), then these data can be used to infer the type of seabed present or characterise the type of community present. For example, solitary coral records presented for the broader Marlborough Sounds region, identify at least 3 solitary coral records for the HS66 survey area (Figure 49). Given that Anderson et al (2020) identified distinct habitat zones where solitary corals occurred – this species is potentially a good indicator of those habitats. Consequently, solitary coral records within the HS66 survey area may provide valuable inference on the type of habitat present at those sites. Many specimen records can also come with counts of abundance[19], which may provide additional insight on where beds of species may occur example 100 scallops, or 25 *Atrina*. A combination of abundance and species types may, therefore, provide more helpful insight into the habitats and communities present. Museum specimen records may take a few months to processes/receive, but generally are a freely available source once permission is granted.

Many of the significant habitats within the Sounds are biogenic for which important information may exist in the biogenic habitat layers used in Anderson et al.'s (2019) Review of NZ's key biogenic habitats, and Lundquist et al.'s (2020) evaluation of Key Ecological Areas (KEA) datasets for the NZ

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[19] Although as described in (Anderson et al. 2019), although there is rarely areal estimates of survey effort, so consequently relative densities are generally not able to be determined from these count records).

Marine Environment. Again, these should be freely available, but requests would need to include a description of how these data would be used.

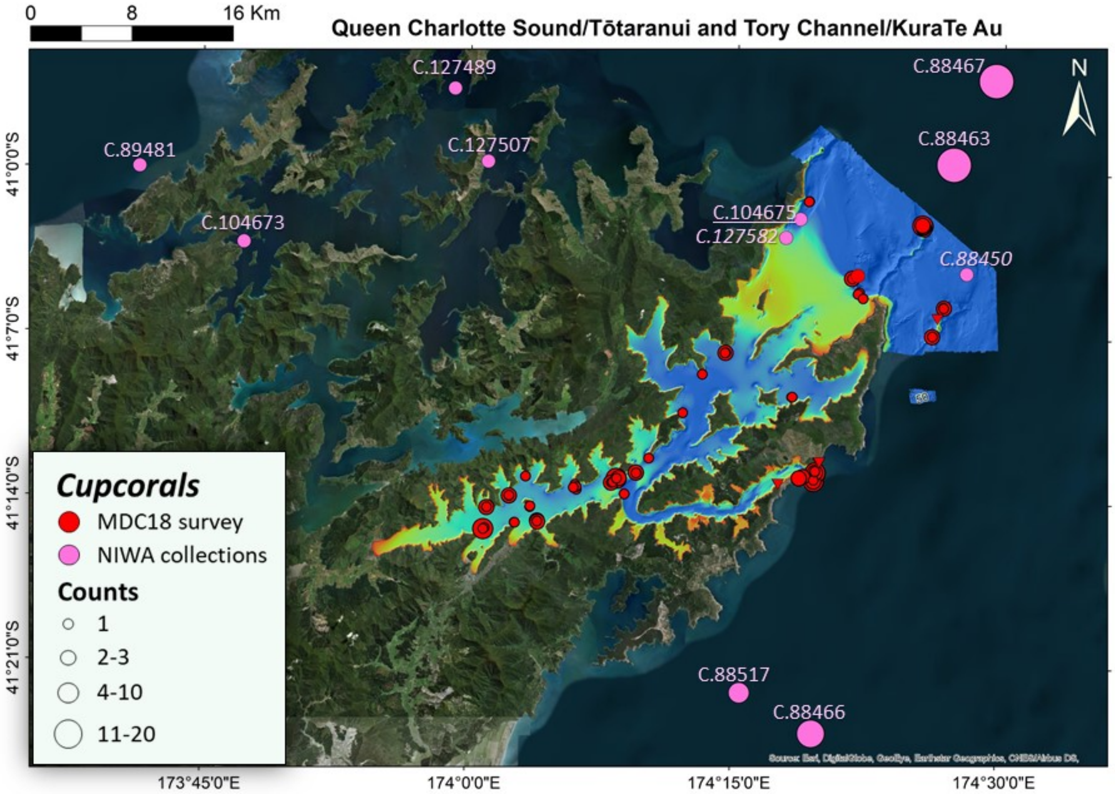

Figure 49. Known distribution of Flabellidae solitary cup corals from (*from Figure 61 in* Anderson et al. 2020c). Pink labels (e.g., C.89481) depict NIWA taxonomic catalogue numbers for *Flabellum* specimen (see Table 9), with species denoted by 'normal font' = *Monomyces rubrum,* 'underline' =*Flabellum knoxi*, and 'italics' = *Flabellum* spp.; Red circles and their size denote cup coral abundance as measured *in* Anderson et al. 2020c.

Table 9. Example of specimen records (here cup corals) known for the HS66 survey area (*from Table 3-22 in* Anderson et al. 2020c). Solitary cup coral (Phylum: Cnidaria, Class: Anthozoa, Order: Scleractinia, Family: Flabellidae) specimens are from NIWA's Specify-invertebrate collection as of May 2019).

Subregion	Cat. No.	Date	Latitude	Longitude	Genera-Species	Depth (m)	Count
PS-mid	104673	14/12/1983	-41.0533	173.7883	*Flabellum* spp.	27	1
PS-out	127489	14/12/1983	-40.9433	173.9850	*Monomyces rubrum*[3]	29	1
PS-out	127507	14/11/1978	-40.9950	174.01669	*Monomyces rubrum*[3]	35	1

4.5.2 Fisheries bycatch data

Similarly, Fisheries NZ/MPI records are also generally freely accessible, but require a full explanation of what the data are to be used for and come with restrictions regarding what scale of information you can plot or report (*so as to avoid any issues with confidentially provided location information*), along with other conditions. However, in some cases, fine scale data can be provided solely for confidential examination (i.e., can't be reported or published), but this would be valuable as a way of discovering the location of potentially important habitats and communities. Again, these requests normally have a lee time of one to several months. However, the bycatch data would be one of the more useful datasets to have access to, especially for:

1) Examining the relationship between the shell debris-fields known / and likely to occur in relation to moderate-to-high seafloor reflectivity (as seen in NIWA's SRC layer). Many of these areas

overlap with the historic scallop fields (Figure 16b) and the Fishing effort and catches of the scallop dredge fishery (Figure 18).

2) Identifying the types of benthic epifauna associated with channel edges and shell-debris habitats that are known and/or inferred to support notable biological communities, particularly in known to have debris-fields armouring the substrata.

Collating recent benthic survey data from published public reports would be a valuable exercise. These should include, but not be limited to, Morrisey et al. (2013) and Brown et al. (2016), and other Cawthron surveys, where these reports are published and publicly available. For example, Morrisey et al. (2013) and Brown et al. (2016) undertook a series of baseline survey of potential new salmon farm sites. Habitat and biological descriptions from these surveys (presented by site) are provided in their report, with GPS positions provided in appendices. These data can 'help' provide valuable ground truthing information for evaluating the seafloor MBES layers, identify where samples already exist, and importantly can contribute to verifying habitats types within the MBES maps to then help extrapolate similar seafloor information relative to known (ground truthed) biodiversity.

4.6 Collection of new data.

4.6.1 Allocating new ground truthing

The manner of allocating ground truthing samples is also important and crucial to ensuring cost effective ground truthing surveys that provide effective management of these ecosystems. Following the previously outlined steps the large-spatial MBES maps can be used to infer the types of habitats that are present on the seafloor. Each of the MBES layers tells us something about the nature of the seabed, and this can be used to infer what the seabed is like. Collecting real observations of the seafloor can then determine if this inference is correct. If information is collected that repeatedly verifies a particular seafloor/habitat type, especially in different spatial locations then this provides high predictability (with lower uncertainty) enabling extrapolation of this habitat type to other areas with the same physical attributes. An adaptative sampling design, helps build up this approach, where some data are used to train habitat models, using either qualitative supervised classifications, or building quantitative predictive models (e.g., BTM classifications and Habitat suitability models and multivariate physical-habitat-community clustering analyses). However, these classifications are only as good as the ground truthing data that has been used to build these models. The more high-quality ground truthing data used, the more the uncertainty of the predictions to new areas can be reduced.

For example, allocating more sites in variable habitat (e.g., transitional and patchy habitats) generally provides more new information than the same number of samples in a more homogeneous habitat (e.g., homogenous muds), where collecting 20 samples in a homogeneous habitat latter tells you little more than collecting three samples. The seafloor regions within the Marlborough Sounds contain a variety of potential-habitat types, with higher reflective seafloor areas likely composed of a mixture of seafloor substrata (Orpin et al. 2020; T. J. Anderson, Stewart, et al. 2020). As a reflection of this, randomly allocating samples across a mapped area is unlikely to capture this complexity, but rather could easily miss critical habitats, and changes in habitat types.

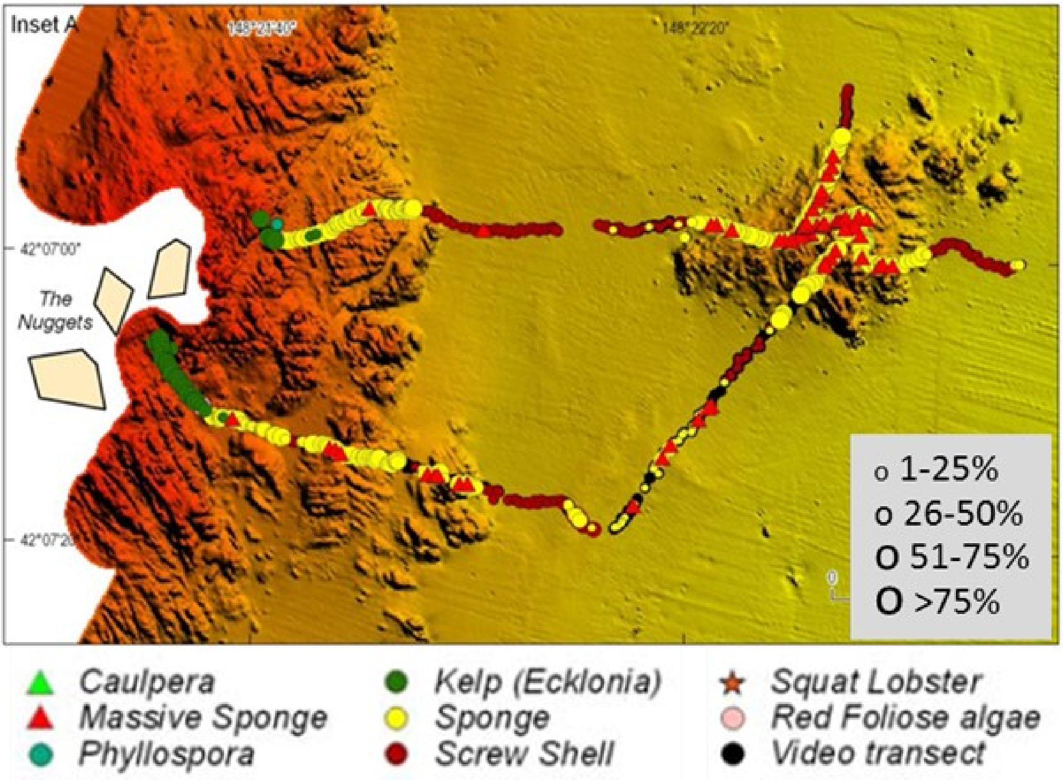

Figure 50. Example of GIS map showing tow-video characterisations for the spatial distribution of important habitat-forming biota In the Freycinet Marine reserve, eastern Tasmania (Nichol et al. 2009). Insert legend: Circle size indicates percentage cover for kelp, sponge and screw shells.

The variation in the different MBES layers provide great insight into this variation, and can also be used to provide valuable insight into designing and planning a cost-effective new ground truthing survey. Seafloor reflectivity classes (i.e., backscatter classes) are one of the useful tools to help guide the allocation of ground truthing samples, but MDC also needs to ensure that these different predicted habitat classes are adequately sampled. Seafloor backscatter provides critical information on seabed composition (i.e., is it hard, moderately hard or soft), but other MBES layers (e.g., bathymetry, rugosity and slope etc.) should also be used to help guide sample allocation, as variability in each of these layers are useful both separately and in unison. Importantly the variability both between and within these classes needs to be adequately assessed across the map. This is particularly important for intermediate and high reflectivity classes depicted in NIWA's SRC, as each of these coloured-classification may represent more than one (possibly many) different habitat types (Orpin et al. 2020).

Ground truthing sediment grab and benthic video surveys are costly to conduct and equally costly to processes. Optimal sampling methods are therefore important to ensure adequate between and within class assessment and representative coverage. While a straight forward stratified random sampling may be sufficient for simple landscape structure, in complex landscapes an adaptive sampling approach may produce better coverage.

New ground truthing surveys should include an **adaptive sampling approach**. This would allow priority sites (e.g., areas most likely to support significant habitats and communities) based on physical proxies (bathymetric features and complexity of the seafloor) to be surveyed first. Once priority sites are surveyed then 2nd tier sites should be surveyed, and so on. The 2nd and 3rd tier sampling plan should have some flexibility to ensure that newly identified significant or notable habitats are adequately characterised, while areas that are observed to be less significant or more homogenous may be down-graded in their survey priority - although more homogenous seafloor habitats still need to include some replication across their spatial distribution). For example, 2nd tier surveying in areas found to be more homogeneous that predicted can be allocated fewer transects or sites than otherwise planned, while areas of unexpected heterogeneity and/or the discover of significant habitats with high biodiversity can be prioritised. As depth is an important variable in structuring community gradients, benthic video transects in sloping environments should be run perpendicular to the depth contour to capture transitions in habitat and communities along these depth gradients.

Benthic video transects be employed within all complex habitats to ensure that the variability (within a zone) and the boundaries of that zone are accurately characterised and delineated. Where significant habitats with high biodiversity or significant species are discovered (e.g., horse mussel beds, bryozoan field, *Galeolaria* mounds/fields, brachiopod beds, sponge gardens), Subsequent video-transects should be run in perpendicular directions across the site to ensure the boundaries of the significant habitat are adequately delineated. Video transects with track-line GPS (i.e., GPS positions recorded every 1-sec along the transects, where positioning is <5-10 m accuracy) are essential, so that when the track-line habitat data is overlaid on the MBES map layers these are correctly aligned, so that the physical correlation of these boundaries can then be used to delineate that full spatial boundary of that significant habitat/community.

The use of drop cameras does not provide the same accuracy of information, except perhaps in homogeneous environments – but even then, one should not assume a priori that areas of seafloor (within a site) predicted to be homogenous (at the horizontal scale of the MBES layers e.g., 1-2 m), are actually homogenous without verifying this directly. Benthic video transects (using any number of methods, including ROV's AUV's or towed-video) are the best way to do this. Drop camera sites can be beneficial in some situations, such as verifying the geology. However, they generally provide less within-site information to characterise biological community composition and habitat and community patchiness, and it can be difficult to map the position and transition rate of community boundaries (i.e., a distinct clear boundary versus a gradual one). Transition rates can often be detected / correlated with changes in MBES map layers so being able to define these in the community structure is often very valuable when linking boundaries to maps. Drop-camera surveys can capture spatial structure where they are undertaken in an intensive spatially explicit approach (e.g., sampling a gridded area at fine scale), however, over the extent of the HS66 region this would be unfeasible. While one could suggest a compliment of the two approaches could be used to optimise effort – such as towed-transect in complex areas and drop camera dispersed over homogeneous areas - the issue of biased sampling that assumes homogeneity cannot be made a priori, and as such should only be used cautiously.

4.6.2 Collection of new TEK

Traditional environmental knowledge (TEK), or Mātauranga taiao, is recent and historic knowledge passed down through oral tradition or shared experience and observations. Many iwi/hapu have a long and intimate bond with their local moana, including marine habitats, taonga, and the mauri of coastal ecosystems. Working with iwi/hapu to describe past and historic areas of ecological importance in their rohe can be extremely valuable. When traditional and western science are integrated this can provide a better understanding of the health and wellbeing of marine ecosystems. As ground truthing data and historic knowledge get overlaid on the new MBES maps across the Sounds, these data layers (as hopefully glimpsed at in this review) can have considerable synergies that give so much more insight into predicting where significant sites of biodiversity are presently, but also how these systems may have changed, and realistic avenues that may help to restore the mauri (life force) to these marine environments.

4.6.3 Online portal for marine 'sightings' (marine animals, plants and habitats).

Marlborough has an active community engaged with the marine environment on many levels. Many people now record observations of what they have seen when on, or in, the ocean. This information is a currently untapped resource. As an excellent example of what can be achieved by harnessing local information, the University of Tasmania run an online portal called RedMap[20] that is helping to extend marine species mapping using public sighting of marine animals and plants. Something like this would provide an excellent resource for MDC and enable the community to contribute to the knowledge base of the sounds. A similar localised version of RedMap could include sightings of both endemic and exotic species, and habitat 'CBED-type' classifications, which would immediately help to extend species distribution and habitat records across the Sounds. An online portal on SmartMaps could allow community user to record their sightings (of fish caught), upload photos for identification (which can be sent off to specialists), with the position (GPS coordinates). This should also include photos of the seafloor, as GPro's become more common, this could provide an amazing resource over time (also see NatureWatch[21]). Species sighting can include marine invertebrates, demersal fish, algae, pelagic fishes, mammal sightings. In the RedMap system, taxonomists across the country have become very engaged too – with automatic notifications sent to relevant taxonomists as sighting are entered - so that they can provide online identification, as this provides valuable information for the taxonomists too, that can be used to document species distributions and range extensions. For example, (D'Archino et al. 2019) review of New Zealand seaweeds includes species distributions from community science sightings. While this might not be a task under the MBES-funding programme it could be a valuable currently untapped resource to draw-on over time.

5 Conclusions/recommendations

MBES analysis requires that each of the MBES layers be critically evaluated. Below is an evaluation of each of the layers already identified as important in predicting seafloor habitats and significant biodiversity. Green ticks are provided to identify whether visual maps (one tick) and quantitative raster data (a second tick) are currently available. A red cross indicates that absence of maps and / or raster data.

5.1 Summary of physical layers

- **Bathymetry (depth)** ✓✓
  Depth is a very important predictor of changes in biological communities. The current bathymetric maps at 2 m, 1 m, and 0.5 m scales are already available (both visually and as quantitative rasters), and can provide great value, in association with other physical raster layers, in visually and quantitatively predicting where seafloor habitat and significant biodiversity might occur.
- **Slope-mean (high=steep slopes)** ✓✓
  Slope angle relative to current speed, and slope angle in relation to rocky reefs were both important variables in predicting different habitat types with significant species, communities and diversity in the eastern Sounds (Anderson, Anderson et al. 2020; Anderson et al. 2020; Anderson et al. 2021; Ribó et al. 2021). The slope maps / raster layers at 2 and 1 m resolutions are already available (both visually and as quantitative rasters).
- **Rugosity (high=rocky outcrops)** ✓✓
  Seafloor rugosity is an extremely valuable predictive variable, as rugose habitats provide structural 3-dimensional habitats that provide potential refuge for species. Highly rugose habitats associated with changes in vertical height changes in the bathymetry are also indicative of rocky reef habitats. Where these habitats occur in locations with high current speeds, one would predict diverse marine assemblages to also be present, although the composition would also be

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[20] Redmap Australia - Redmap

[21] https://www.rnz.co.nz/national/programmes/ourchangingworld/audio/201803460/citizen-science-large-brown-seaweeds

expected to vary with distance from the entrance to Pelorus Sounds/ Te Hoiere (e.g., mixed filter-feeding communities likely dominated by sponges would be predicted on outer current-swept Pelorus Sounds/ Te Hoiere reefs, while taxa such as hydroid trees would be predicted to characterise inner Pelorus Sounds/ Te Hoiere reef). The rugosity maps at 2 and 1 m resolutions are already available (both visually and as quantitative rasters).

- **Slope-stdev (high=rough)** ✓✓
  In both the HS51 and HS66 survey areas, the standard deviation of the slope (slope-stdev) has proven to be a very valuable layer to help infer and delineate low-lying rough habitats (i.e., where rugosity is also low, but where slope-stdev is high inferring rough seafloor habitats).

  Slope-stdev can help qualitatively (and hopefully in the future quantitatively) identify areas of seafloor roughness that predictively support significant habitats, such as bryozoan patch-reef areas (e.g., Figure 39, Figure 40 and Figure 41), shell debris habitats (e.g., Figure 31, Figure 36 and Figure 45), and cobble or biogenic rubble fields (e.g., broken *Galeolaria* mounds). These types of low-lying rough habitats include significant biological communities with often very high associated biodiversity, with some biogenic known to be important nursery habitat for juvenile blue cod along with juveniles of several other species (e.g., Black and yellow triplefins, dwarf gurnard and leatherjackets) (Anderson et al. 2019; Anderson et al. *in prep.*; *pers. obs.*). Bryozoan patch-reef zones at both channel entrances to QCS and possibly now at the entrance to Pelorus Sounds/ Te Hoiere; and rough shell-debris fields in the extensive channel area west of Allen Strait, north of Sugar Loaf Is, have all been identified (or predicted) based on higher levels of roughness in this layer. The slope-stdev maps at 2 and 1 m resolutions are already available (both visually and as quantitative rasters). The creation of a secondary classification category for 'rough-habitat zones' would help to classify low-lying rough and biogenic habitat areas, that may support a variety of significant communities and elevated biodiversity (incl. bryozoan patch-reefs). This layer would be similar in form to the 'rock outcrop layer' in the HS51 seafloor mapping project; and would complement a new-revised 'rock outcrop' layer for the HS66 data.

- **Mean current Speed (high= current swept habitats)** ✓$^{\underline{90\%}}$✓$^{\underline{90\%}}$ **(no French pass)**
  Near-bottom current speed is an important driver of seafloor habitats, community types, and benthic biodiversity ((McArthur et al. 2010; Buhl-Mortensen et al. 2012). Current-swept areas have also been shown to support diverse communities both on hard rock outcrops and on soft-sediment areas that offer some form of biogenic structure or debris for diverse epifauna to settle (e.g., Davidson et al. 2010, 2011, 2022). The distribution and abundance of significant and diverse communities were also correlated with high near-bed current speeds in several different habitat types within the eastern Sounds (Anderson, Anderson et al. 2020; Anderson et al. 2020; Anderson et al. 2021; Ribó et al. 2021). Presently, 90% of the HS66 survey as has mean near-bottom current speed, however the mapped area of French Pass was not included in this model. The two options here, are 1) investigate the options and associated costs of extending the model to include /French Pass; or 2) drop French pass from any quantitative modelling. As French Pass is likely to support some of the most significant biogenic habitats with possibly some of the highest biodiversity in the Sounds (*pers. obs.*), it is recommended that this subregion be included in the modelled mean near-bottom current speeds. If costs of this are prohibitive then treating French Pass separately is a possible option, as this subregion already has considerable information available to predictively (based on visual interpretation of MBES maps) delineate habitats and communities.

- **BTM classifications** ✓
  These should be fully evaluated across the entire HS66 survey area, and also assessed against all other layers. Access to existing ground truthing data (metadata shown here but data not yet available) may help to target areas of uncertainty in these maps. However, while all, or even some, of the 14 geomorphically-classed zones may be valid, it is important to realise that these

may not directly represent significant biological habitats. As seen in the HS51 surveys the geomorphic classifications failed to align with almost any biological patterns, although in some localised zoomed in instances some boundary lines (on some sides of the habitat) were helpful in delineating a few habitats/communities. However, on the whole these classifications were generally not overly useful. Given the similarities between the eastern and western Sounds, and the preliminary examinations of these data layers for the HS66 survey area, it is likely that these BTM classification (with the exception of a revised rock outcrop class=10 category) will provide little predictive insight into where significant habitat and their biodiverse communities might occur.

- **Rock outcrops layer (polygon area=reef)** **XX** **- Not avail., but readily created**
  The ability to accurately delineate rocky reef areas is an important product for MDC to have. This would enable estimates of rocky reefs to be calculated for i) the HS66 survey area; ii) different sections of Pelorus Sounds/ Te Hoiere, and in association with a new high rugosity layer would enable the calculation the relative availability of high rugosity versus low rugosity rock areas. This different rock features are extremely important, in association with other layers such as current speeds, in predicting community composition and biodiversity levels. Currently the 'rock outcrops' layer extracted from the BTM for class=10, is from initial evaluation relatively accurate at broad-scales (capturing rock area), but at fine scales does not give a 1:1 boundary relationship, and also incorrectly denotes notable-sized areas of non-rock habitat. For some sites a relatively good match was observed, but for other sites the match was ~45% wrong. This has major consequences when 'stocktaking' / calculating the amount of rocky habitat available. Therefore this rock outcrop layer should be revised following the methods used for the HS51 survey area by Neil et al. (2018), which includes using BTM classification, high rugosity and seafloor curvature. This layer should then be re-evaluated against the ground truthing data, and adjusted / fine-tuned to ensure the best fit possible.
- **Grain size analyses / sediment composition (mud, sand, gravel).** **XX** (*but see* **NIWA's SRC)** ✓
  Sediment grain size composition can be an important predictor of community types and their boundaries (often based on threshold boundaries) (Snelgrove et al. 1994; Snelgrove, 1999; Anderson et al. 2004). In New Zealand, for example, in the southern Taranaki Bight, Beaumont et al. (2015) discovered a spatial extensive infaunal tubeworm field that was strongly correlated with a narrow range of fine grain sizes; and found that threshold values in grain size could be used to delineate this significant habitat/community type. Sediment grab samples are costly to collect and equally costly to process (analyse for grain size). In the HS51 survey, processed grain size was used to train (66% of ground truthing HS51 sediment grab sampling sites) the seafloor reflectivity classifications, and validate (33% of HS51 sediment grab samples) the SRC maps. In addition, as part of the habitat suitability modelling for *Galeolaria* and bryozoan patch-reefs, the % sand, gravel and mud values were each interpolated across the entire HS51 mapped area (cropped by MBES coverage), and examined relative to large spatial patterns in sediment composition (pers. obs.). The abundance and spatial distribution of *Galeolaria* was weakly predicted by the %sand (grain size) variable, but not for bryozoan patch-reefs.

  Sediment grain size analyses would be useful to have, and are valuable for accurately describing surficial sedimentological features. In terms of NIWA's SFR layer, 1) the final HS51 seafloor reflectivity classifications were trained and verified on the HS51 datasets. These corroborated data relationships were then used to classify the same four seafloor reflectivity classes in the HS66 data. Given the similarities between the Eastern and Western Sounds, this approach was sagacious. Sediment samples were then collected, targeting increased levels of reflectivity, to ground-truth this variability in this 'new' and 'untested' region. The 'new' preliminary[22] CBed classifications appear to adequately validate NIWA's four seafloor reflectivity classifications (i.e., based on the pre-modelled relationship between sediment composition and the MBES- HS51 backscatter data - full methods described in Neil et al. 2018; Orpin et al. 2020). Several options are available to MDC.

i. MDC can use the CBed classifications as 'good-enough' validation of the SRC maps. This is sound in terms of the biology, but if geological interpretations of sediments are also required then one of the next options would be required.

ii. 33% of the ground truthing sediment grab samples could be analysed for grain size and used to the validate NIWA SRC for the new HS66 survey area. This would adequately reflect the validation method used by Neil et al. (2018).

iii. Alternatively, all sediment grab samples could be processed for grain size analyses, used to validate the SRC mode/layer, and then sediment composition (%sand, mud, gravel) would also be available for inclusion in predictive biological modelling.

It is however important to realised / remember that sediment composition (based on grain size) is inherently modelled within NIWA's seafloor reflectivity classifications (i.e., low reflective muds to high reflective gravels and hard substrata), and therefore for the most part NIWA's SRC, for both the HS51 and HS66 areas, supersedes the use of the sediment composition variables (%muds, sand and gravel) on their own.

However, having said the above, it is also important to note that in the HS51 *Galeolaria* habitat suitability modelling project, NIWA's HS51-SFR layer was very noisy up the slopes of QCS, mostly due to lots of reflective signals, and noise, associated with the upper slope high relief rock outcrop, and the presence of moderately high reflectivity of the hard-tubed mounds and hard broken tube rubble within the *Galeolaria* mound zones, but also due to relatively high reflectivity from shell debris both armouring the seafloor on the upper slopes, but also buried under increasing amount of fine depositional muds on the lower slopes. This high reflectivity noise (in the SRC too) meant that discerning suitable habitat zone for *Galeolaria* across the slope was problematic. The inclusion of the interpolated %sand variable helped discriminate mud shell on the lower slopes from sandy gravels on the upper slope. The final combination of variables resulted in a great model fit of the observed *Galeolaria* distributions and abundance.

➢ **Backscatter imagery (high=hard reflective surfaces)** ✓**Field-processed only for areas 1-4** ✗ **none for area 5**
Backscatter imagery (*even the rough field-processed backscatter from iXblue for their four subregions*) is very valuable to visually infer different substrata types. Backscatter processing, using methods such as FM-Geocoder Toolbox, has been sequentially improving their processing methods to compensate for different signal strength across the swath; but also variations between different survey methods, etc.) to improve the overall comparability of signals across the mapped area. Mackay et al.'s (2020) overview of the backscatter data collection methods and calibrations has resulted in a high-quality backscatter dataset and in their words is now 'fit for scientific research' but that this data needs to be fully processed. In addition to backscatter calibration sites being used to ensure that the two survey vessels were in sync (in terms of comparable backscatter data collection), NIWA also ensured that the backscatter data collected in the HS66 survey area was calibrated with the backscatter data collected in HS51 survey area. This was an excellent approach and have ensured that backscatter and Seafloor Reflectivity Classifications are fully comparable. This has important consequences for the SRC approach NIWA has taken for the HS66 backscatter reflectivity classifications (see next point, below). It is

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[22] Preliminary here meaning that CBed classifications of primary and secondary habitat types, and shell-debris-rank were based on well-presented descriptions in (Orpin et al. 2020), without viewing the imagery (sediment photos and dropcam video footage) directly – which I would recommend the final classifications would need.

recommended that the HS66 backscatter data be fully processed.

- **NIWA preliminary SRC (high=hard reflective surfaces)** ✓Map Image x - raster created but not available
  This data layer appears to be a very good if not excellent match with the new ground truthing data – although further more formal evaluations of this would be required. This layer was also identified to be an important predictor of many significant taxa and community types within the HS51 survey area. Based on preliminary examination of similar relationships within the HS66 survey area, the HS66 SRC layer would be an important predictor of seafloor habitat types, and therefore an important predictor of benthic communities and biological diversity. The new CBed substratum and the shell-debris rank %cover variables were extremely valuable visual tools to assess and interrogate seafloor biodiversity, along with other MBES layers. The close match between the four reflectivity classes and the observed CBED characterisations indicates that NIWA's 'preliminary' SRC layer is already 'fit-for-purpose' (e.g., Figure 23, Figure 24, Figure 35 and Figure 36).

  However, while the geo-rectified tiff can already be used to interrogates these maps in terms of predicted areas of significant habitats and biodiversity, the ability to include this layer in predictive habitat suitability modelling relies on the raster data of this layer being available. If not, it is likely that the backscatter will need to be re/fully-process independently (as recommended above in the backscatter point) using the same four level reflectivity classification scheme to create a new SRC raster layer.

- **Water column data (some inference to kelp forests)** x - not processed/raw data only
  Mackay et al.'s (2020) overview of the water column data collection methods and calibrations has resulted in a high-quality dataset that is 'fit for scientific research' but that this data has not yet been processed. While the water column data would provide an interesting research project and may provide some valuable knowledge on kelp forest locations, its overall value in determining significant sites of biodiversity is very low – based on its examination during the HS51 ground truthing programme (Anderson et al. 2020). In the HS51 survey area, high amounts of variability and erroneous records of kelp where no kelp was present were found across the HS51 survey area, but especially large volumes of invalid *in situ* macroalgal records were recorded throughout Tory channel and its tributary embayment's - due in-part to large areas of drift algae being lumped together and reported as attached growing macroalgae, which resulted in predictions of kelp beds out over expansive mud embayment's where no reef exists. Excessive amounts of drift kelp were common in Tory Channel embayment's and also occurred around the entrances of Tory Change and QCS. However, these large volumes of drift kelp (generated by detached seaweed from Tory channel and adjacent Cook Strait kelp forests) are not known to occur in Pelorus Sounds/ Te Hoiere. Although, if accumulated algal mats are present, the processed water column data may help to verify this previous-undocumented habitat type.

  Targeted examination/processing of the water column data, however, around the entrance to Pelorus Sounds/ Te Hoiere might be of greatest benefit to MDC, as this might help to identify the presence of any large extensive kelp forests (similar to those discovered on the outer headlands of QCS), and, to see if *Caulerpa* forests might be detectible (using training dataset from the HS51 data). This type of targeted approach would definitely be a priority if water column data were to be examine/processed further. The headlands around the entrance to QCS and Pelorus Sounds/ Te Hoiere are extremely exposed and very hard to ground truth even on a flat calm day at slack tide (*pers. obs.*). Consequently, the ability to remotely map/detect 3-dimensional structure (i.e., kelp forests and *Caulerpa* beds) above the reefs would be extremely valuable in these very significant but very hard to survey sites

- **Spatial predictors.** **xx - Not avail., but readily created**
  Several spatial variables were created in ArcGIS to be used in the Habitat suitability modelling

projects (Anderson, Anderson et al. 2020; Anderson et al. 2021). 'Distance to nearest headland' was created as a measure of the nearest distance from a channel associated headland (point at the tip of each headland + ridgeline). 'Distance to nearest Reef' was measured using the rock outcrops layer. Noting here that any error in the rock outcrops layer (i.e., missing reef, or a reef polygon where not reef occurs) would obviously negatively affect the validity of this measure. 'Distance to nearest Reef' was important for species not directly associated with reef habitats but the presence of a reef was important (e.g., *Galeolaria* and *Thyone* spA, Anderson et al. 2020c, 2020b). These two variables are likely to be equally valid within the Te Hoiere/ Pelorus Sound survey area. In addition, other spatial predictors, such as 'Distance from the main Pelorus Sounds/ Te Hoiere channel' and 'Distance from Cook Strait entrance' will likely help discern and model spatial patterns already seen in the new HS66 survey area.

5.2 Summary of biological next steps

5.2.1 Request & collate existing data

A critical step in analysing the MBES data, would be to collate all existing ground truthing data (where available). This should include as much biological information as is practicably accessible such as existing benthic survey data, museum specimen records, and other local knowledge datasets. All sites and data should be collated in an ArcGIS data base, and mapped over the MBES layers to review to help identify spatial patterns and correlations in these data sets. This approach can provide a wealth of information to help characterise seafloor habitats, communities and species. This information should also provide insight into the interpretations of the underlying seafloor MBES map layers, and will help ensure that new ground truthing sites are allocated in the most efficient way, and do not duplicate existing ground truthing. Based on the reviewed metadata and preliminary ground truthing data presented in this report, the following data should be collated:

- **HS66-2020 Ground truthing imagery:** the HS66 video footage and photos of sediment-grabs are a very important resource. They should be used to interrogate, validate and correlate with these MBES-HS66 layers, and to help determine where new targeted ground truthing sites should be located.
- **Museum/specimen records:** All specimen records for the greater Marlborough Sounds be requested. This should include requests to: Te Papa, Auckland Museum, Australia Herbarium, NIWA Specify (NIWA's invertebrate database) and OBIS (which is currently managed by NIWA, Wellington). Macroalgal records should be requested from NIWA Seaweeds database (managed by NIWA Wellington).

  These data records will require some data grooming and collation. After collation the data will need to be clipped by the land coverage (to remove any marine specimen records that erroneously plot over land), checked and corrected for duplicate records (i.e., museums often share records from some source) and then clipped by the MBES-HS66 coverage, and then checked against the MBES layers for any obvious site errors.
- **NZ Fishery Records:** bycatch records of marine benthic specimen for the Marlborough Sounds.
- **MDC's benthic survey data:** Collate all the benthic survey data collected under MDC funded projects, for example: The benthic sites and survey data associated with Rob Davidson's Significant sites surveys (e.g., Davidson et al. 2022); and the *Mycale* sponge discovery survey data (Page and Handley, *unpublished data; pers. comm.*). For these sites could then be classified/recoded as CBED primary and secondary classifications types, to enable these data to be mapped comparably to those in Figure 23. In addition (secondarily), any information that could enable CBed-characterisation of sites by key species and community types (e.g., Figure

25a,b), would be very valuable.

- **Marine Farm Surveys:** data from all available marine farm survey sites should be collated. This collated dataset once mapped over the MBES-layers should provide valuable information of what habitats are present in and around marine farm areas, and can how they correlate to the MBES-HS66 maps.
- **Other benthic survey data**, Metadata presented here, identifies numerous benthic surveys that have been undertaken within the HS66 survey area. These datasets are owned by various Agencies/Institutes and 3rd parties. Here, it will be important to evaluate the cost associated with getting access to these other data sources. Requests (as with above) should include information to (at least) enable the site to be classified/recoded as CBED primary and secondary classifications types, so data can comparably be mapped (e.g., Figure 23). These data sources would include, but not limited to: i) Cawthon's benthic video survey data, and their inside and adjacent to farm (and potential farm) sites (e.g., Figure 9; Figure 26, Figure 27, Figure 28); ii) MBIE-funded 2017 Bottlenecks surveys[23];

5.2.2 Analysis of MBES layers using the existing ground truthing data

Once the existing data has been sourced, cleaned and collated, these data should be converted into primary and secondary CBed Substratum type classifications, and where biological data are also provided these should be recorded as species presence records. These data should then be converted to shapefiles and plotted in ArcGIS to be used in the analysis, evaluation and interrogation of the MBES-HS66 map layers. Specifically, these ground truthing data be used to:

1) **Correlate and verify the preliminary Seafloor Reflectivity Classifications** (SRC). preliminary examination of these layers, show that there is good alignment / correlation between the new ground truthing CBed-classifications and NIWA's SRC layer, although, more specific and systematic examination is still required. The shell-debris rank classification (*cream-coloured bubble-sizes in* Figure 24) and the % gravel grain size data from inside and outside marine farms (*grey-coloured bubble-sizes in* Figure 24; *also see sediment composition pie-charts in* Appendix A-Figure 53), also both align extremely well with the higher reflectivity areas depicted by NIWA's SRC layer. This combination of layers also provides considerable insight into the physical driving forces (i.e., current speed) that form these shell-debris zones on the seafloor. There is also good ground truthing evidence that the very high current-zones in and beyond the Pelorus Sounds/ Te Hoiere entrance are characterised by whole-shell debris that armour / cover the seafloor. Similarly, the current-scoured channels on either side on the entrance are also characterised by varying amounts of whole-shell debris. Examination of the HS66-2020 video footage along with sediment grab photos, would likely provide much better information to enable shell-debris characterisation along the inner to outer main channel of Pelorus Sounds/ Te Hoiere. There is likely to be some variation in the amounts of whole-shell debris at the surface of the sediment (that is likely important for epifaunal taxa) versus shell debris and shell hash buried at part of the mud matrix in other higher reflectivity mud habitats (which is unlikely to provide similar surface-available habitat for epifauna).
2) **Correlate and verify NIWA's BTM classifications (BTC).** The available data can be used to zoom in on various locations and examine how well the BTM classifications correlate with observed habitat types. A good correlation is not expected over the large spatial extent of the HS66 survey[24], however valuable information to be gained from visually examining fine-scale

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[23] This programme funding was from Oct 2017 to Oct 2020, after which these data should be publicly available.

[24] As there was generally not much visual relationship (and very little analytical correlation) between the spatial location and delineation of the BTM and the significant and notable communities

correlations. Based on the lack of correlation in the HS51 survey area, and similar issues based on the preliminary HS66 evaluations during this review, the BTM layer is not recommended for predictive modelling without further validation in terms of it match with seafloor features.

3) **Examine and verify LEK polygons**. This report provides a very preliminary examination and review of the 21 delineated Local Ecological Knowledge (LEK) polygons depicting eight key biogenic habitat types within the HS66 survey area (Figure 43 and Table 7). Initial examination of these data relative to all other available ground-truthing data (as presented in this review), are that several of these LEK polygons align very well with newly (MBES-HS66) mapped bathymetric features and/or correlate with colour-differentiated patterns in the geo-referenced image of NIWA's preliminary SRC layer. Preliminary examination of what metadata is currently available would also help evaluate whether these key biogenic habitats are still present. Targeted ground truthing as part of a planned survey assessing these historic LEK sites would also be valuable.

4) **Identify 'new' sites of important marine biodiversity.** The wealth of information in the new map layers enable the seafloor within the HS66 survey area to be examined in great detail (like never before). This report presents some preliminary examinations of several example areas, sites and ground truthing datasets. These examples evaluate the application of ground truthing data available, both in respects to historically-described habitats and any recent data that might verify the presence of predicted or identified key biogenic habitats and significant sites.

5) **Predict/infer important habitats from the MBES maps.** The more ground truthing characterisations of seafloor habitats and their communities that can be accessed, converted into CBed classifications and plotted over the MBES maps, the better the ability to predict new notable and significant areas of biodiversity; and the less effort required to collect new data[25]. Existing data also helps to better target new ground truthing sites. This ground truthing data may then be used to highlight complex seafloor areas with predicted high-value habitats.

6) **Integrate new / revised MBES layers**: This review has recommended and described other new derived-MBES-layers and revisions and changes to existing MBES layers (as described above). Once these layers have been created, the new CBed classification layers can be plotted over these new MBES layers (and combined with any additional ground truthing data that can be accessed from metadata identified above), to interrogate these new map layers for other significant habitats with inferred biodiversity significance.

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[25] Unless getting access to 'existing-data' cost more than collecting new ground truthing data in the same locations.

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7 Glossary

Term (use)	**Definition**
Benthic	Associated with the seafloor.
Biodiversity	The variability among living organisms from all sources; this includes diversity within species, between species and of ecosystems.
Biogenic	*"Produced or brought about by living organisms"* The Oxford English Dictionary (2018).
Biogenic habitat	Physical habitat created by living organisms, such as coral reefs, oyster beds, tubeworm reefs, kelp beds, seagrass beds.
Colonial	Animals that live as a part of one physically connected colony, such as corals, bryozoans and some tubeworms and tunicates.
DEM	Digital Elevation Model. A three-dimensional grid representation of the shape of the earth (seafloor or land) surface.
Depositional sediments	The build-up of sediments deposited on the seafloor over a period of time. Source of dispositional sediment can include fine sediment from the water column and sediment movement down slope, such as landslides.
Dredging	Towing a device over the seafloor primarily for the collection of shellfish.
Epifauna	Animals living on the surface of the seafloor.
ESMS	Ecologically Significant Marine Sites as defined in MDC 2019. Previously referred to as Ecologically Significant Sites [ESS] as defined in Davidson et al. 2011 and 2015.
GIS	Geographic Information System. Computer software for the handling of spatial data, and advanced data manipulations and analysis.
Habitat	The environment where an individual, species or group of species live that can be repeatedly found in nature.
MBES	Multibeam Echosounder (MBES)
MBES-HS66	Multibeam Echosounder (MBES) Hydrographic Survey No. 66 (HS66), LINZ Project HYD-2018/19-01 (HS66) Hydrographic Survey of the western Marlborough Sounds: French Pass and Admiralty Bay / Te Aumiti and Pelorus Sounds/ Te Hoiere
MBES-HS51	Multibeam Echosounder (MBES) Hydrographic Survey No. 51 (HS51), also referred to as: LINZ Project HYD-2016/17-01 (HS51) Hydrographic Survey of the eastern Marlborough Sounds: Queen Charlotte Sound / Tōtaranui and Tory Channel / Kura Te Au.
MDC	Marlborough District Council.
Polygon	An area fully encompassed by a series of connected lines. In this review depicting (or predicting) an area where a habitat occurs within.
Relict	Of biological original, but no longer living (e.g., The remaining tubes, shells or hard structures of animals now dead).
Raster (in ArcGIS)	A raster is a numerical spatial dataset composed of an array of equally sized cells arranged in rows and columns (grid), where each cell contains a numerical value representing information such as elevation, temperature, or rugosity.

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Appendix A. Ground truthing CBED classifications by survey type.

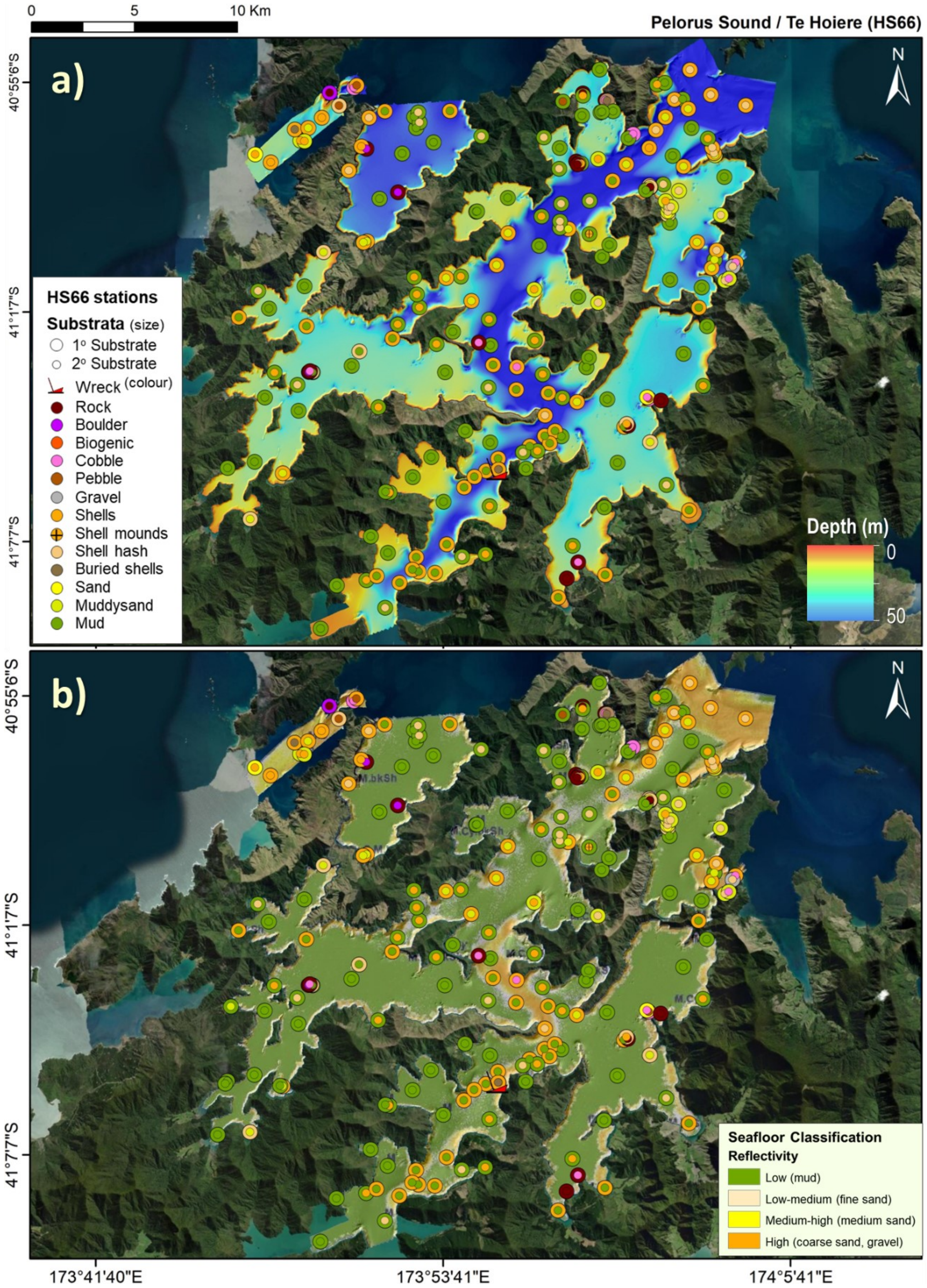

Figure 51. Primary and secondary substratum types for HS66 ground truthing sites (collected by NIWA, iXblue and DML) overlaid on the HS66 bathymetry (a) and NIWA's Seafloor Reflectivity Classification (SRC). Here, sites represent sediment grab and/or dropcam sites, with primary (large circles) and secondary (smaller inner circles) substratum type characterised based on information presented in Appendix A-C in Orpin et al. (2020). The SRC layer is a geo-rectified image of NIWA's preliminary SRC (Neil et al. 2018; Orpin et al. 2020).

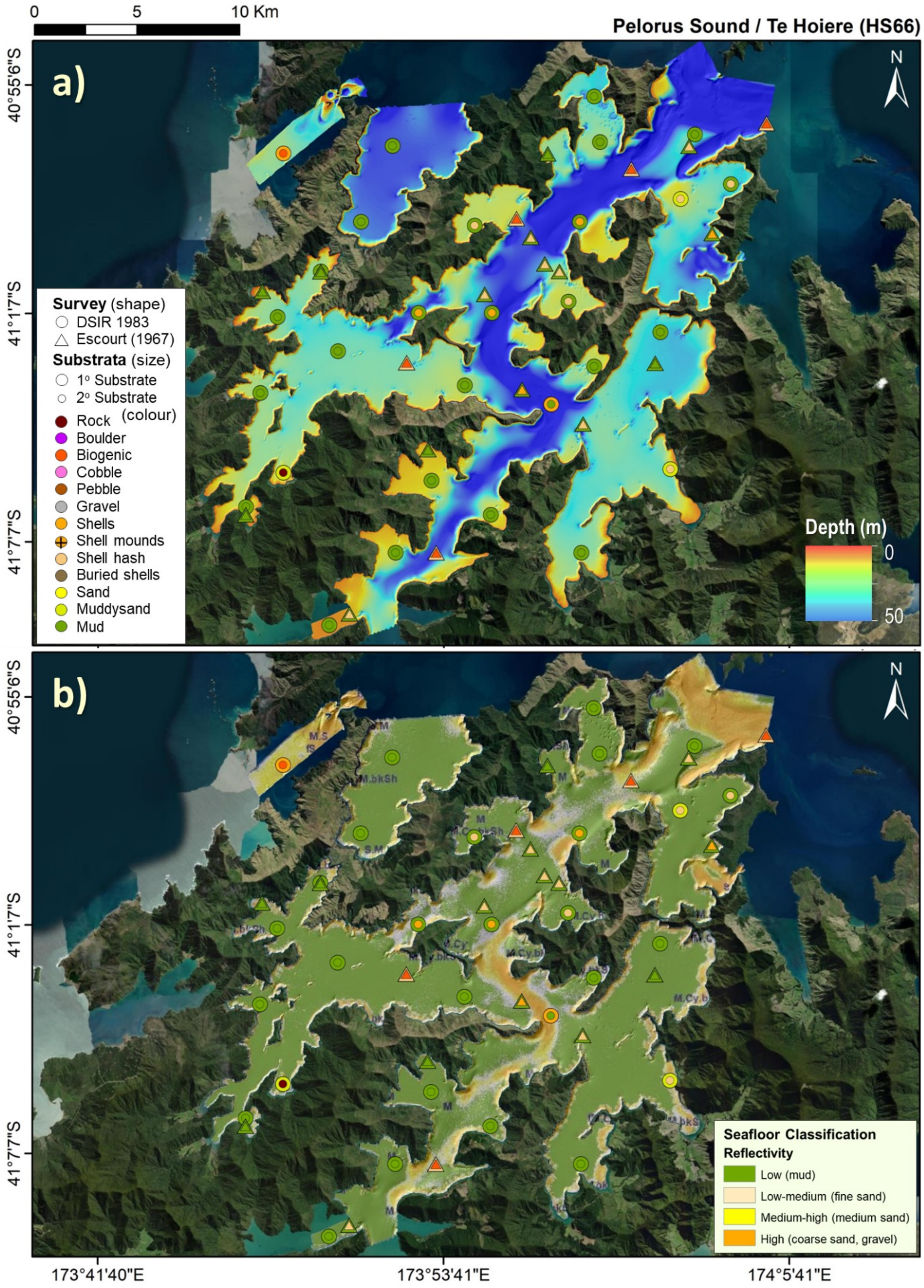

Figure 52. Primary and secondary substratum types from two historic biological surveys: Estcourt (1967) and DSIR 1983 (McKnight et al. 1991a), overlaid on the HS66 bathymetry (a) and NIWA's Seafloor Reflectivity Classification (SRC)). Here substratum type has been recorded based on bottom characteristics recorded and/ or inferred from the types of biota collected. The SRC layer is a geo-rectified image of NIWA's preliminary SRC (*see caption in* Figure 5; methods outlined in Neil et al. 2018; Orpin et al. 2020).

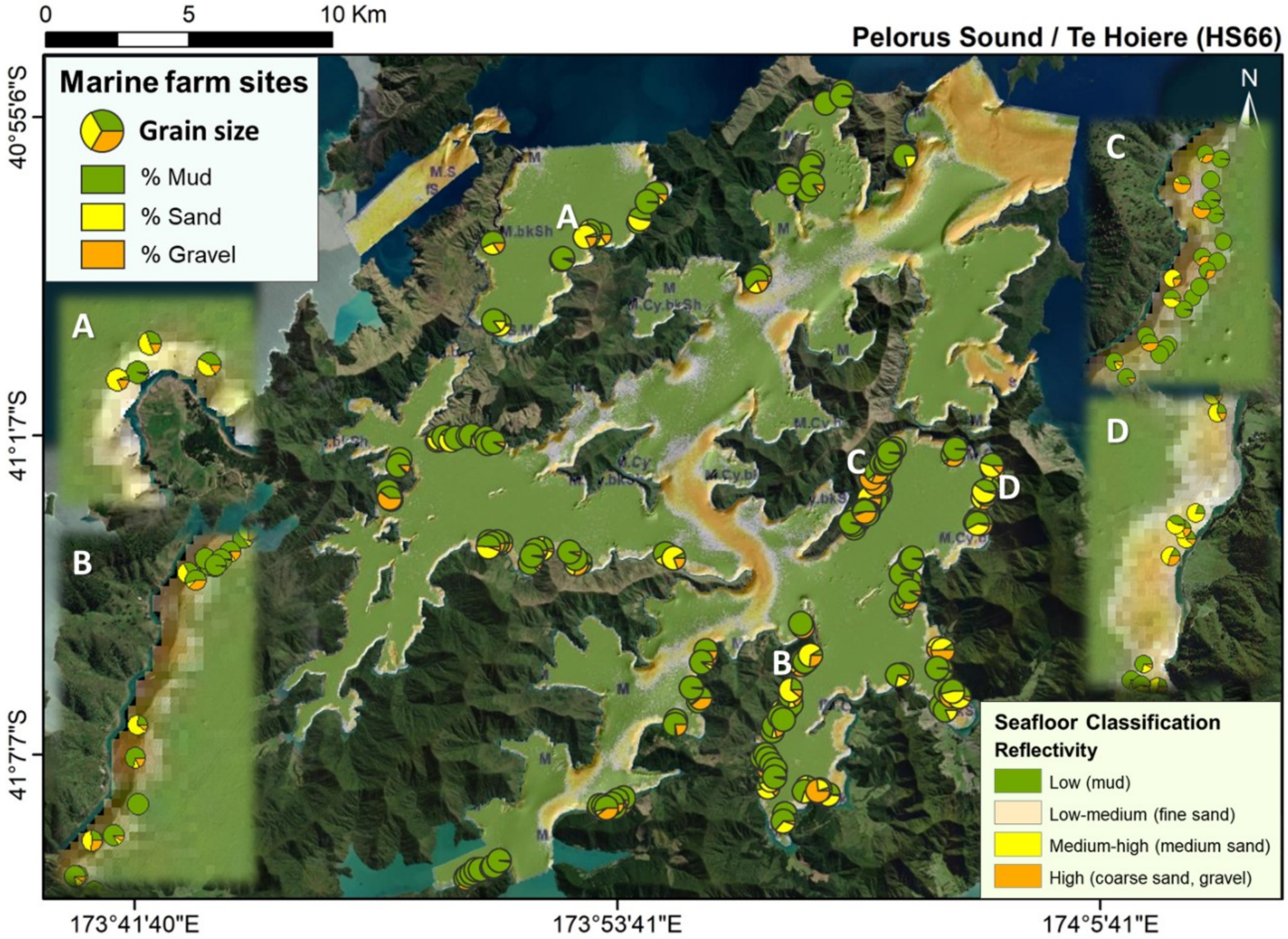

Figure 53. Grain size composition of percent mud, sand and gravel at benthic survey sites from inside and/or near marine farms. Data is from RMA reports held on the MDC Aquaculture farm SmartMaps system (https://smartmaps.marlborough.govt.nz/smapviewer/?map=6af1f32120314f569f780dafba2647cf). Inserts A-D represent zoomed in areas depicted in the main map. NB: Figure 24 presents the % gravel component of these sediment samples relative to the shell-debris rank estimates created for the from the HS66-ground truthing surveys.