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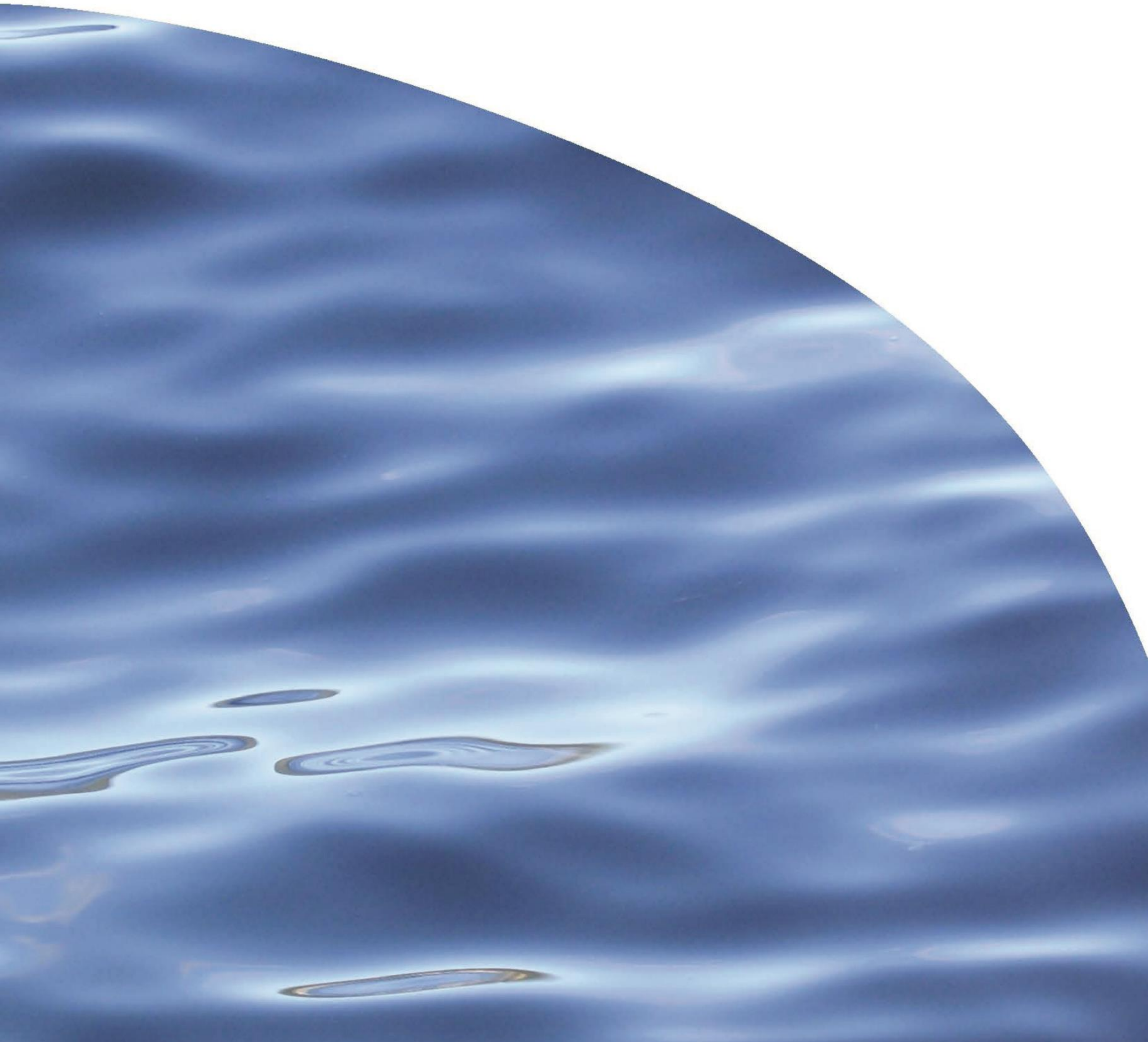
REPORT NO. 3047

BENTHIC HABITAT ASSESSMENT: NORTH ARM, PORT PEGASUS / PIKIHATITI



BENTHIC HABITAT ASSESSMENT: NORTH ARM, PORT PEGASUS / PIKIHATITI

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Prepared for Ministry for Primary Industries

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EXECUTIVE SUMMARY

Finfish aquaculture has been identified as a leading opportunity for economic and social development within the Southland region. The New Zealand government is committed to supporting well-planned and sustainable aquaculture growth, and are proceeding with a three-stage process to investigate this opportunity. Stage 1 assessments have identified the North Arm region of Port Pegasus/Pikihatiti (located at the southern end of Stewart Island/Rakiura) as potentially suitable area for development. Cawthron Institute was commissioned by the Ministry for Primary Industries and the Ministry of Business, Innovation and Employment to undertake further investigations on site suitability within the North Arm area to determine the suitability of the area for finfish farming operations. Stage 2 assessments included both benthic habitat and pelagic biophysical assessments (presented as separate reports).

The benthic habitat assessment focused on seabed areas that were likely to be of suitable depth for finfish farming. The survey aimed to determine the distribution of soft-sediment habitats, the location and size of offshore reefs identified, and the presence of habitats or taxa considered to have significant ecological, scientific or cultural value. Broad-scale habitat characterisation was achieved through a combination of sonar imagery, drop-camera and video sled footage and benthic grab sampling. Key findings regarding the benthic habitat assessment of the North Arm region are summarised below:

- Soft-sediment habitats within North Arm were separated broadly into two areas: an area to the north of Pearl Island, with sediments comprising higher proportions of mud particles and with mud-tolerant infaunal communities; and an area to the west of Pearl Island, with sediments having higher proportions of sand particles and infaunal communities more tolerant of the coarser substratum.
- Patch reefs with diverse invertebrate and fish assemblages extended into the mid-channel area from Bens Bay, as well as additional areas surrounding Chase Head.
- Soft-sediment habitats supported relatively sparse epifaunal assemblages (i.e. animals living on the seabed), when compared to similar semi-sheltered inshore environments around Stewart Island/Rakiura.
- Isolated areas of high epifaunal diversity were noted, in particular the coarse sand/cobble habitat identified near to the entrance to Whale Passage.
- Several taxa of ecological significance were identified within the surveyed area, including brachiopods, black coral, sea pens, tube-dwelling anemones and several large bivalve taxa.
- In general, taxa of ecological significance were sparsely distributed (< 1 per 10 m^2), and largely centred across areas of mud substrates to the north and northwest of Pearl Island. However, patches of greater abundance were found closer to patch reefs and within cobble habitats near to the entrance of Whale Passage.
- Macrofaunal communities present within North Arm are broadly representative of similar unimpacted environments elsewhere. Across the North Arm region, total

abundance and species diversity was lower in sand substrates through Big Ship Passage, particularly when compared to mud substrates to the north of Pearl Island.

- Enrichment Stage (ES) scores were generally low across the North Arm region, reflecting natural conditions in the range of low-to-minor enrichment. In general, ES scores were slightly higher in the muddier sediments north of Hells Gates, possibly due to the close proximity of these sites to riverine inputs.

Results of the benthic habitat assessment outlined above were used to prioritise potential locations for finfish farming operations within the North Arm region. Circular exclusion ‘buffers’ were placed around areas of hard substrate or coarse-grained sediments and areas containing potentially sensitive taxa, as identified through sonar imagery and drop-camera transects. To provide additional guidance on suitable locations for potential farm sites, the Index of Suitable Location (ISL) for finfish farming was calculated for the entire North Arm area, based on depth and water current data. Results of the ISL analysis indicated that mid-channel areas in Big Ship Passage have the greatest potential for farming, when taking into account exclusion buffers and optimising water depth. Four potential farming areas (c. 10 ha each) were subsequently selected within Big Ship Passage, along with a smaller smolt growing area (c. 1.3 ha) at the northern coastline.

Depositional modelling, combining physical properties of water currents with farm configuration and production parameters, was used to predict the potential distribution and intensity of waste product (i.e. uneaten feed and faeces) deposition to nearby benthic habitats. In addition, depositional modelling provided an indication of the production capacity of the region, while staying within benthic guidelines with regards to associated seabed enrichment levels. Depositional modelling was carried out in isolation from any other considerations (e.g. water quality, natural character, landscape and visual amenity). Two sets of scenarios were modelled, based on the farming areas operating in a similar way to either low-flow or high-flow sites within the Marlborough Sounds region. This does not suggest that farm sites are ‘high-flow’, rather that some of the sites may be ‘low-flow sites with episodic wave action’ which may have a mitigating effect on benthic enrichment. The magnitude of that potential beneficial effect is currently unknown. The use of the high-flow assumption is for comparison purposes only, and does not suggest that the potential effect from waves would be of similar magnitude as high-flow tidal currents in the Marlborough Sounds. The ‘high-flow’ based scenarios and their associated potential production figures should therefore be interpreted with caution. For the depositional modelling, the total number of pens at each site was varied to achieve lower production levels, which were calculated using a feed conversion efficiency ratio of 1.7:1.

Under low-flow scenarios, production estimates of between 2,800 and 6,000 tonnes per year were possible, while adhering to benthic Best Management Practice (BMP) guidelines. Deposition beneath the pens, and beyond, was predicted to be at levels that are likely to be assimilated by the benthic communities in the lower feed-input scenarios. Higher rates of deposition were predicted assuming the seabed could assimilate farm waste similar to that observed at high-flow sites. The higher rates predicted were due to the slight overlap in depositional footprints from each pen, and the increased feed input per pen under high-flow scenarios. Seabed enrichment within these small patches was predicted to reach very high levels and would be at the upper limit of enrichment effect allowed under the BMP guidelines, provided the farms performed like high-flow sites. The low-flow nature of the smolt site resulted in relatively high rates of deposition, concentrated largely beneath the pens. Excessive enrichment was predicted directly beneath the pens in some scenarios; however, beyond the pens the deposition of farm wastes was at levels likely to be assimilated by benthic communities.

If finfish farming is deemed appropriate in North Arm, a staged approach to development is recommended. This is due to the low-flow nature of the area and uncertainty around the effects of wave action on the seabed beneath the proposed farming areas near the entrance to Big Ship Passage. Detailed, site-specific 'Stage 3' assessments are recommended once final farm locations are decided. These assessments would recommend initial and predicted sustainable feed inputs to each of the sites. The BMP guidelines are recommended as an initial framework for monitoring and managing seabed effects. Due to uncertainty around the role that wave action will play in seabed enrichment trajectories, some site-specific adjustments to the BMP may be necessary over time. However, several years of seabed monitoring would be needed to guide any site-specific adjustments to the BMP guidelines. Careful management of feed inputs would be necessary at all farming sites, to ensure benthic effects remained within BMP guidelines. The use of benthic management tools (e.g. fallowing, seabed remediation, waste capture) may be possible to mitigate benthic effects, with long-term environmentally sustainable outcomes the priority. However, most of these tools are in the early stages of development and have yet to be tested at commercial scales in New Zealand, and each has environmental costs that require consideration. Fallowing has been tested in Marlborough, but requires additional farm space that increases the area of seabed affected by deposition. Waste capture and seabed remediation have been tested at a research scale in New Zealand, but both require the regular transport and disposal of large amounts of farm wastes, either at sea or in landfill.

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ABBREVIATIONS

AEE	Assessment of environmental effects
AFDW	Ash-free dry weight
BMP	Best Management Practice
DEPOMOD	Depositional modelling
DOC	Department of Conservation
EQS	Environmental Quality Standards
ES	Enrichment Stage
ISL	Index of Suitable Location
MBIE	Ministry of Business, Innovation and Employment
MDS	Multi-dimensional scaling
MPI	Ministry for Primary Industries
PSFL	Predicted sustainable feed level
RIFL	Recommended initial feed level
SIMPER	Similarity percentage analysis
SoRDS	Southland Regional Development Strategy

1. INTRODUCTION

1.1. Background

The Southland Regional Development Strategy (SoRDS) has identified opportunities for economic and social development within the Southland region. The strategy identifies aquaculture, in particular finfish aquaculture, as a leading opportunity for regional development. The New Zealand government is committed to supporting well-planned and sustainable aquaculture growth in New Zealand. As such, the Ministry for Primary Industries (MPI) is conducting a three-stage process to the investigate this opportunity. Preliminary scoping investigations conducted by the Cawthron Institute (Cawthron) suggested that the North Arm of Port Pegasus/Pikihatiti (see Figure 1) may be suitable for finfish farming from a bio-physical and ecological perspective (Clark et al. 2015; Elvines et al. 2015; Elvines et al. 2016). In addition to North Arm, 12 sites[1] along the eastern coastline of Stewart Island/Rakiura were investigated. However, all other sites presented a number of limitations with regards to water depth, wave exposure and the presence of sensitive benthic habitats. Following these Stage 1 assessments, MPI have commissioned further investigations on site suitability within North Arm, to confirm the environmental and commercial feasibility for finfish aquaculture in this area (Stage 2).

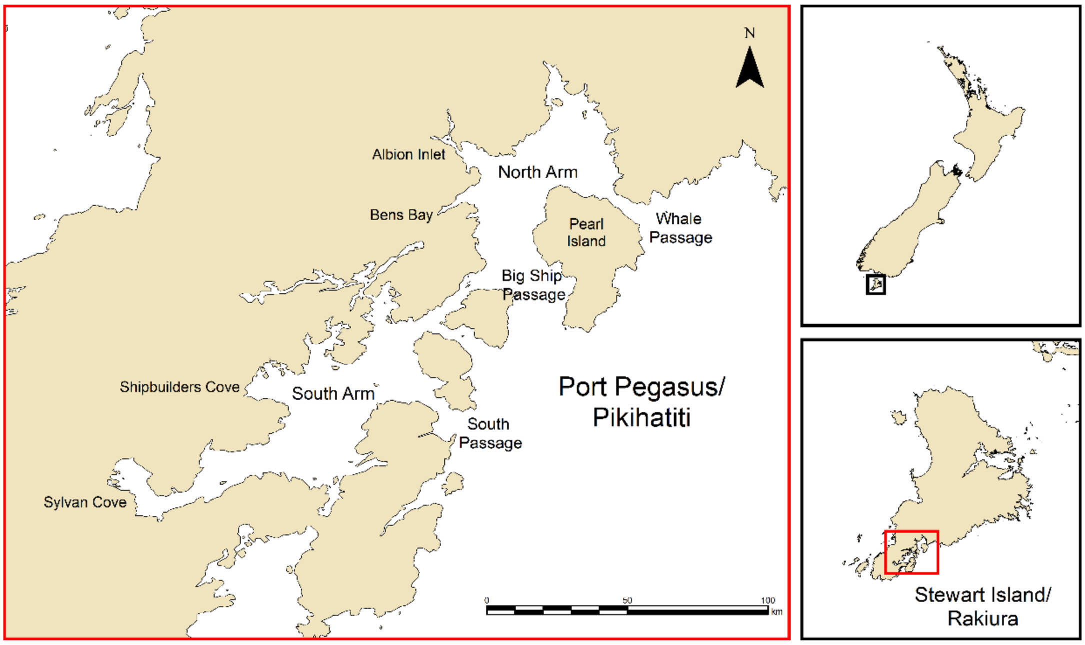

Figure 1. Map of Port Pegasus/Pikihatiti showing the North Arm and South Arm regions, as well as oceanic connections and key features of the area. The location at the southern end of Stewart Island/Rakiura is indicated.

[1] Port Adventure, Paterson Inlet, Big Glory Bay (2 sites), South Arm of Port Pegasus/Pikihatiti, Tikitahi, Owen Island, Weka Island, Chew Tobacco Bay, Horseshoe Bay, Lee Bay and Lords River.

1.2. Project scope

In March 2017, MPI and the Ministry of Business, Innovation and Employment (MBIE) contracted Cawthron to undertake Stage 2 assessments within the North Arm region of Port Pegasus/Pikihatiti to determine the suitability of the area for finfish farming operations. Stage 2 assessments included both benthic habitat and pelagic biophysical components; however, only the results of benthic habitat assessments are presented here. Results of the associated pelagic biophysical work are presented in a separate report (Knight et al. 2017).

It should be noted that the benthic assessment does not directly address the natural character values of the benthic environment within North Arm. The survey was focussed on the distribution of soft-sediment habitats, the location and size of any reefs away from the shoreline, and the identification of taxa that would be considered to have significant ecological, scientific or cultural value. Specifically, this document provides:

- broad-scale habitat characterisation from sonar imagery
- benthic habitat visual assessments using drop-camera and video sled footage, including ground-truthing of features identified through sonar imagery
- identification of selected taxa deemed be sensitive to anthropogenic impacts, with broad indications of location within the surveyed area and associated density
- characterisation of the physico-chemical properties of soft-sediment habitats and associated macrofaunal communities
- identification of potential locations for finfish farming operations within the North Arm region, based on the benthic survey data outlined above
- assessment of predicted impacts to associated benthic habitats based on modelled depositional footprints from a set of farm layout scenarios.

1.2.1. Proceeding to Stage 3 assessments

Information provided from Stage 2 assessments (including assessments on pelagic biophysical features, economic considerations, and natural character, landscape and visual amenity) will be considered by MPI, MBIE, and other parties (including the Department of Conservation, Ministry for the Environment, SoRDS, Southland Regional Council), and a decision will be made regarding proceeding to the final stage of assessment. Stage 3 assessments would involve additional survey and research work to inform an assessment of environmental effects (AEE) to ensure compliance with the Resource Management Act.

2. PORT PEGASUS / PIKIHATITI

Port Pegasus/Pikihatiti is located near the southern tip of Stewart Island/Rakiura (Figure 1). The area comprises two relatively sheltered water bodies: North Arm and the larger South Arm, which are joined by the narrow Pegasus Passage but each with independent connections to the open ocean. North Arm is connected to the open coast to the south by Big Ship Passage and to the east by the narrower Whale Passage. The main oceanic connection to South Arm is through South Passage. North Arm has relatively deep water with steep drop-offs present along the majority of the coastline. The greatest water depth (c. 50 m) is found to the northwest of Pearl Island. The remainder of the mid-channel waters are between 30-40 m deep. North Arm is relatively exposed to wave action through Big Ship Passage, but Pearl Island in the east provides shelter from the easterly and south-easterly swells. South Arm is more sheltered and relatively shallow in comparison (c. 20-28 m water depth).

There is no permanent human habitation within Port Pegasus/Pikihatiti, although a small settlement was present at the northern end of North Arm from the 1890s to the 1950s. This settlement was centred on a small fish factory, with the remains of the concrete wharf from this endeavour still present. More recently, Port Pegasus/Pikihatiti has become a destination for tourism and remote experience expeditions, including recreational hunting and fishing. There are anecdotal reports of historic and more recent recreational dredging for scallops and oysters within North Arm. However, reports are conflicting and at present it is not possible to quantify the nature and extent of this activity.

2.1. Stage 1 assessments and comparison to other Stewart Island sites

As part of Stage 1 assessments, Cawthron undertook a preliminary benthic survey within the North Arm region during August 2016 (Elvines et al. 2016). We surveyed five areas using a video sled and sonar imagery. The majority of the flat seabed in these areas was found to consist of fine sands and mud substrata. Areas of coarse sand and cobble with some large boulders were identified close to Whale Passage and along the northwest shoreline. Offshore reefs were identified northwest of Pearl Island, offshore from Bens Bay and close to Whale Passage. A range of epifaunal taxa were observed in the video footage. Commonly-observed taxa included sea cucumbers, brittle stars, sponges, brachiopods, hermit crabs and gastropods. Less commonly observed taxa included fanworms, anemones, and unidentified bivalves. Horse mussels, urchins, tubeworms, scallops and flat oysters were observed, but were rare (Elvines et al. 2016).

Video surveys of the Port Pegasus/Pikihatiti marine environment have also previously been undertaken as part of a Department of Conservation (DOC)-contracted project during November 2011 and May 2012. The video was initially used for fish census purposes (Haggitt et al. 2013), and more recently re-analysed to classify abiotic habitats observed and identify species of particular interest (Laferriere 2017). The assessment included a combination of drop-camera footage, baited underwater video drops and diver surveys. Within the North Arm region, surveys were carried out off the northern point of Pearl Island and on a large patch reef situated towards the middle of the bay. A wide range of abiotic habitats were observed in both areas including rocky reef, sand and mud substrates. Sensitive taxa observed included brachiopod beds, black coral, ascidians and macroalgal beds (Laferriere 2017).

Initial scoping investigations by Cawthron indicated a relative lack of biota present on soft-sediment habitats within North Arm when compared to similar environments around Stewart Island/Rakiura (i.e. Paterson Inlet, Port Adventure, Big Glory Bay, South Arm) (Clark et al. 2015; Elvines et al. 2015; Elvines et al. 2016). Initial potential finfish farming areas surveyed (February and August 2015) included the Refuge Area at the entrance to Big Glory Bay, four sites within Port Adventure, and a site further south at Tikitahi. The site at Tikitahi was found to be too exposed to be considered. The areas within Port Adventure and Big Glory Bay were also deemed unsuitable for aquaculture development, due to both water depth and current flow limitations as well as the presence of dense red algal beds supporting a wide range of fish and invertebrate species (Clark et al. 2015; Elvines et al. 2016). Further surveys within Paterson Inlet, the South Arm region of Port Pegasus/Pikihatiti and adjacent to Bravo Island at the entrance to Big Glory Bay have also deemed these areas unsuitable due to relatively shallow water depths and low current flows, as well as the presence of diverse epifaunal communities. Sites within Paterson Inlet and the entrance to Big Glory Bay had high abundances of brachiopods, tubeworms, sponges, and queen scallops (*Chlamys delicatula*). Similarly, high numbers of brachiopods were observed within the South Arm sites, as well as sea pen fields, sponges, hydroids and red algal tufts (Elvines et al. 2016).

3. METHODS FOR SEABED CHARACTERISATION

Fieldwork for the benthic survey was undertaken between 28 March–6 April 2017 from the charter vessel *Takaroa II*. Cawthron's small research vessel *Kotare* was used for sonar imagery and accessing shallower areas along the coastline.

3.1. Constraints and limitations of the survey

The objective of the benthic habitat assessment was to achieve adequate spatial coverage in order to detect and describe the broad distribution of habitat types within North Arm. As such, the survey was largely limited to soft-sediment habitats and the mapping of any patch reefs that extend into soft-sediment areas. Habitat assessments were constrained by boat access to shallow and often exposed areas, and as such, all were carried out in > 6 m water depth. Very shallow soft-sediment habitats are therefore likely to be underrepresented in the results. The survey does not include quantitative assessments of fish or other highly mobile species.

3.2. Sonar imagery and bathymetry

Sonar mapping of the North Arm was carried out from the vessel *Kotare*. We used a Lowrance Structurescan HD® system with down and side-scanning sonar (455 kHz and 800 kHz frequencies) to map dominant seabed features. The sonar system was towed at 1.5–2.5 knots and had a swathe width of 200 m (100 m either side). Sonar mapping was conducted along predetermined parallel transects running north to south throughout the North Arm (Figure 2). Transects extended to the outer limit of Big Ship Passage and the entrance to Whale Passage. In addition, the inner coastline of the North Arm area, including the entrance to all inlets and embayments, was also mapped.

Sonar imagery was processed using the Reefmaster 2.0 software package to convert the sonar files to geo-referenced sonar mosaics for overlay in GoogleEarth. Outlines of benthic features (i.e. reefs, cobbles, coarse sand) were traced in GoogleEarth using the polygon feature. Polygons were exported into ArcMap v10.4.1 software as a geo-referenced shapefile, enabling the identification of potential farming areas least likely to impact benthic features within North Arm (see Section 5).

Depth sounding data were collected concurrently with sonar imagery. Tidally-corrected depth data from both Stage 1 (Elvines et al. 2016) and Stage 2 assessments were analysed. Tidally-corrected sounding points from LINZ were also used where available. Data were processed in ArcMap v10.4.1 to create a bathymetric chart with depths at mean sea level (MSL).

3.3. Benthic habitat visual assessments

3.3.1. Drop-camera assessments

Video imagery was used to ground-truth features identified through sonar mapping. High-definition surface data-feed video equipment with inbuilt lighting was deployed at specific drop-camera sites positioned along the same pre-determined transects used for sonar mapping (Figure 2). Assessments were made at 200 m intervals along each transect, excluding areas where hydrodynamic equipment was currently deployed. Additional drop-camera assessments were undertaken from Cawthron's research vessel *Kotare*. These included specific areas of interest, including a patch reef within the mid-channel area and the western shoreline of Pearl Island. In total, 245 sites were assessed over a four-day period.

At each site, the drop-camera was lowered over the side of the vessel until the seabed was visible, then allowed to drift for c. 30 seconds. The footage was viewed live from the vessel, and notes on habitat type (i.e. mud, sand, cobble, reef), any significant features and conspicuous epifauna were recorded. Video files were later analysed for specific habitat type classifications and identification of epifaunal taxa observed. A similar seabed classification index to that used in a recent Department of Conservation (DOC) assessment was applied to ensure consistency (Laferriere 2017). Relative abundance scores were assigned for notable taxa, based on qualitative density estimates at each site: absent, not observed; sparse, isolated individuals; patchy, 2–3 individuals in close proximity; moderate, several individuals in close proximity; and abundant, dense aggregations (see Section 4.4 below).

A hard-drive writing error meant that 61 video files were corrupted during recording of three video transects. However, additional video footage taken from *Kotare* as well as video footage taken during the Stage 1 assessment often overlapped the affected area. As such, 11 of the 61 sites (or a site in the near vicinity) were still able to be formally assessed. An estimate of the benthic habitat at the remaining 50 sites was made based on sonar imagery data, information from nearby video sites and from notes taken at the time of assessment. All estimated benthic habitats are clearly identified on each of the subsequent maps.

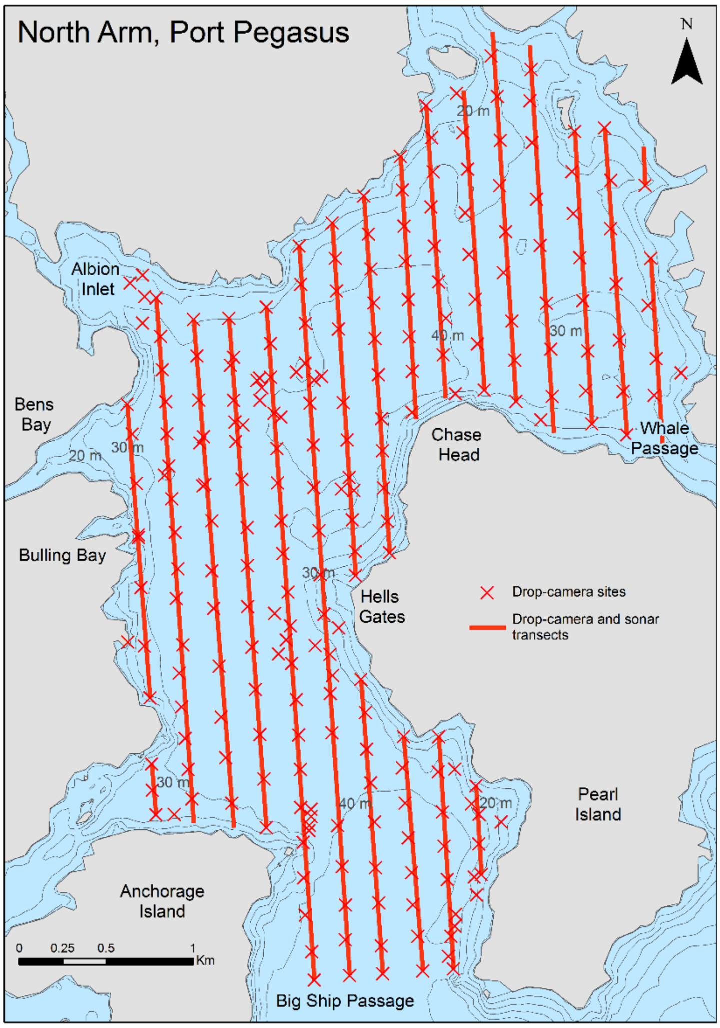

Figure 2. Transects for drop-camera assessment and sonar mapping of the benthic environment in North Arm, Port Pegasus/Pikihatiti. Transects were spaced approximately 200 m apart. The locations of drop-camera assessments are indicated by red crosses.

3.3.2. Video transects

In addition to site-specific drop camera assessments, continuous video footage from 10 transects was collected to map areas of particular interest in greater detail (Figure 3). Transects were carried out within Big Ship Passage (1 transect, c. 770 m length), over a patch reef in the middle of the bay (5 transects, c. 50–120 m length), and off the coast from Chase Head, at the northern end of Pearl Island (4 transects, c. 150–480 m length). The transects off Chase Head were specifically targeting black coral, as this taxon had previously been reported from this location (Laferriere 2017). Transect footage was assessed in its entirety. Habitat features and associated biota were recorded for 60-second intervals. However, when a habitat transition or biota of note was observed, data were recorded more frequently. Sections of footage without associated GPS data (i.e. portions of the transect where the GPS feed were not recorded) were not included in analyses.

3.3.3. Video footage from Stage 1 assessment

Additional benthic habitat footage was obtained from video sled transects undertaken during the Stage 1 assessment (Elvines et al. 2016). Video footage from 25 transects was analysed at 60-second intervals to provide greater spatial resolution for the distribution of benthic habitats types and notable biota (Figure 3). GPS data were available only for the start and end points of Stage 1 transects; as such, the placement of 60 second interval data points are estimated. Lastly, GoPro footage that was collected simultaneously with video sled footage was also assessed. The GoPro footage is not geo-referenced so it is not possible to identify the exact location of the seabed being filmed. Therefore, this footage was used to provide a broad representation of epifaunal taxa present in the general area.

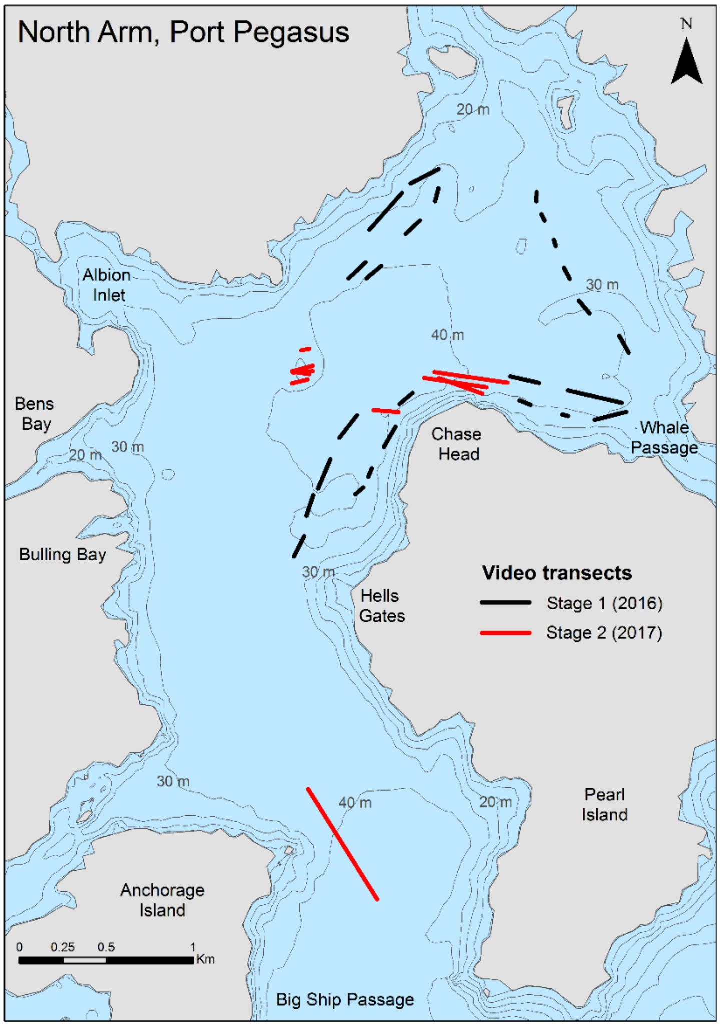

Figure 3. Video transect effort within North Arm, Port Pegasus/Pikihatiti. Transects from Stage 1 (Elvines et al. 2016) and Stage 2 assessments are indicated.

3.4. Physico-chemical properties and macrofaunal communities

Sediment cores were collected using a van Veen grab sampler at 45 sites spread across North Arm for determination of physico-chemical properties (Figure 4). Each grab sample was examined for sediment colour, odour and texture. Two Perspex™ sediment cores (63 mm internal diameter) were collected from each grab sample and photographed to provide a permanent visual record. The top 30 mm of one sediment core was analysed for organic content (as % ash-free dry weight; AFDW). The top 30 mm of the other core was analysed for particle size distribution, using a seven-fraction grain-size analysis. Redox potential (Eh_{NHE}, mV) was measured directly from the grab at using a probe at a depth of 10 mm depth. Brief method descriptions for the physical and chemical analyses are provided in Appendix 1.

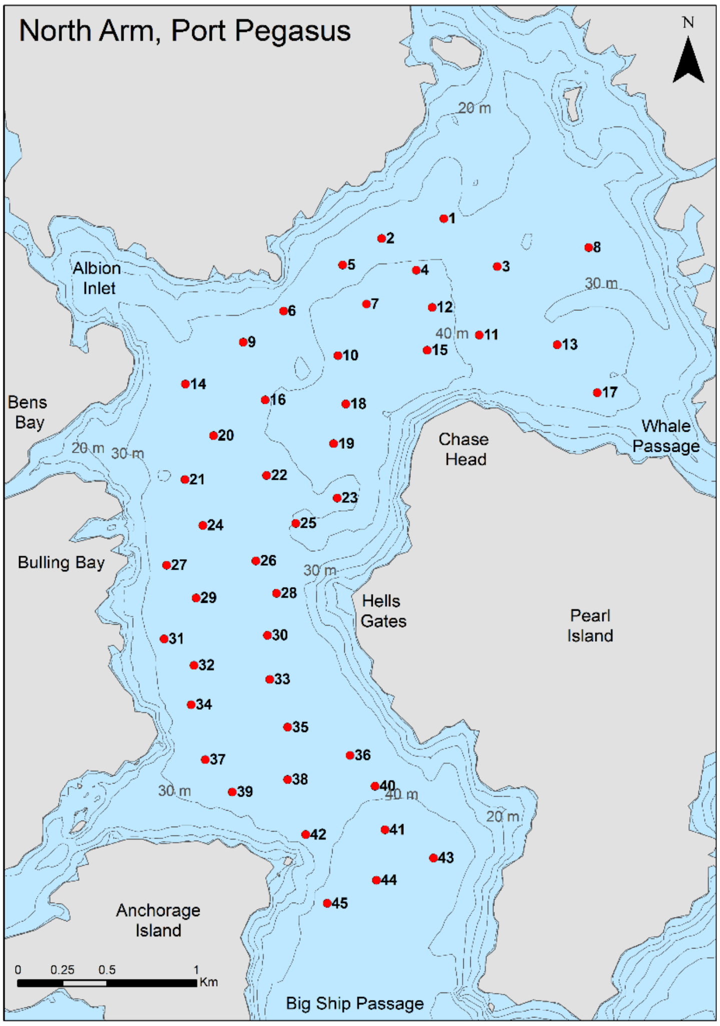

Figure 4. Benthic grab sampling locations within North Arm, Port Pegasus/Pikihatiti.

A separate core (130 mm diameter, ~100 mm deep) was collected from each grab to describe the macrofaunal community assemblages. Core contents were sieved to 0.5 mm and preserved in a solution of 70% ethanol and 5% glyoxal. All samples were processed at Cawthron for identification and enumeration. Raw data were analysed to calculate total abundance and total number of taxa, as well as a range of biotic indices. An explanation of each of the biotic indices is provided in Appendix 2.

Macrofaunal assemblages in each sample were then compared using non-metric multi-dimensional scaling (nMDS) and cluster diagrams based on Bray-Curtis similarities (Clarke and Warwick 1994). Abundance data were fourth-root transformed to de-emphasise the influence of the dominant species (by abundance). The major taxa contributing to the similarities of each group (spatial areas) were identified using similarity percentage analysis (SIMPER; Clarke 1993). All multivariate analyses were performed using PRIMER v6 software (Clarke and Gorley 2006).

3.5. Assessment of seabed enrichment

Seabed condition can be placed along an enrichment gradient which has been quantitatively defined according to Enrichment Stage (ES; see Figure 5), which is a derivative of multiple physico-chemical and biological variables. Seven ES are identified along a gradient from natural conditions to severe enrichment (ES 1-7; Table 1). The ES score is a benthic environmental indicator, with regards to organic enrichment of the seabed, and was developed with reference to salmon aquaculture in the Marlborough Sounds region (Keeley et al. 2012a). The expected changes in macrofaunal community composition and abundance associated with salmon farm enrichment are well documented (Brown et al. 1987; Kalantzi and Karakassis 2006; Macleod and Forbes 2004), and are consistent with organic enrichment response from other sources (Pearson and Rosenberg 1978).

Environmental data (i.e. results of sediment and infauna sampling outlined in Section 3.4) for the 45 benthic grab sites within North Arm were converted into an equivalent ES score using previously described relationships (Keeley et al. 2012a). Scores were first calculated for each of: total organic matter, redox potential and various macrofauna indices (see Appendix 2). Combinations of these values were then averaged to provide scores according to the ES scale of 1 to 7 for each of the following categories: (1) organic loading, (2) sediment chemistry, and (3) macrofauna. Weightings[2] and averaging were used to combine the three scores into a single overall ES score for each site. Weightings are based on best professional judgement, taking into account the relative strengths of their association (see Keeley et al. 2012b). A full explanation of the ES score index, its calculation, and its use as an environmental quality standard can be found in the Best Management Practice (BMP) guidelines for salmon farming (MPI 2015).

[2] Weighting used in the current workings was: organic loading = 0.1, sediment chemistry = 0.2, macrofauna composition = 0.7.

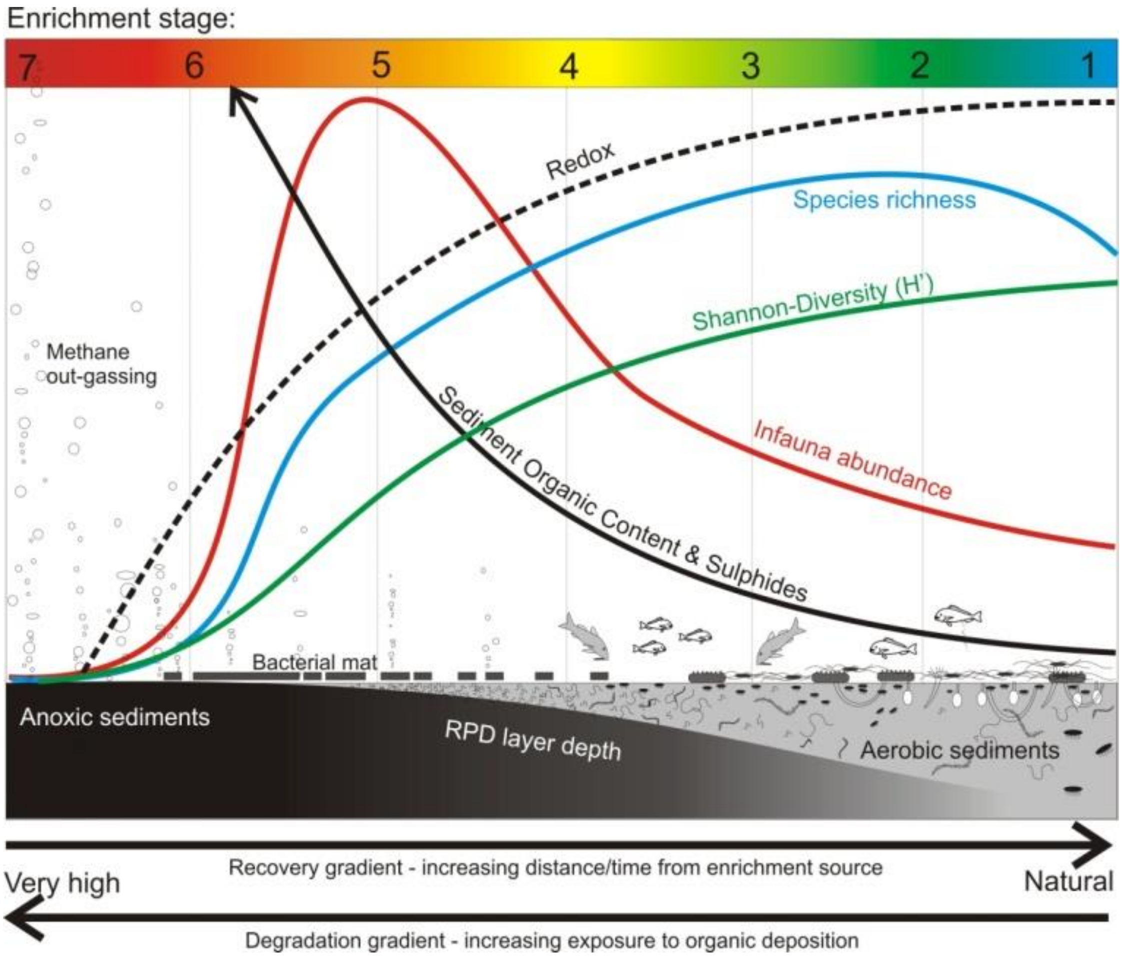

Figure 5. Stylised depiction of a typical enrichment gradient (from Keeley 2013), showing generally understood responses in commonly measured environmental variables (species richness, infauna abundance, sediment organic content, sulphides, redox). The gradient spans from natural conditions (ES 1) to highly enriched azoic conditions (ES 7).

Table 1. General descriptions and primary environmental characteristics for the seven enrichment stages (see Keeley et al. 2012a, 2012b). HF = high-flow sites (mean mid-water current speeds ≥ 10 $cm.s^{-1}$), LF = low-flow sites (mean mid-water current speeds < 10 $cm.s^{-1}$).

ES	General description	Environmental characteristics	
1.0	***Pristine end of spectrum.*** Clean unenriched sediments. Natural state, but uncommon in many modified environments	LF	Environmental variables comparable to an unpolluted / un-enriched pristine reference station.
		HF	As for LF, but infauna richness and abundances naturally higher (~2 × LF) and %organic matter (OM) slightly lower.
2.0	***Minor enrichment.*** Low-level enrichment. Can occur naturally or from other diffuse anthropogenic sources. 'Enhanced zone.'	LF	Richness usually greater than for reference conditions. Zone of 'enhancement'—minor increases in abundance possible. Mainly a compositional change. Sediment chemistry unaffected or with only very minor effects.
		HF	As for LF
3.0	***Moderate enrichment.*** Clearly enriched and impacted. Significant community change evident.	LF	Notable abundance increase; richness and diversity usually lower than reference station. Opportunistic species (i.e. capitellid worms) begin to dominate.
		HF	As for LF
4.0	***High enrichment.*** Transitional stage between moderate effects and peak macrofauna abundance. Major community change.	LF	Diversity further reduced; abundances usually quite high, but clearly sub-peak. Opportunistic species dominate, but other taxa may still persist. Major sediment chemistry changes (approaching hypoxia).
		HF	As above, but abundance can be very high while richness and diversity are not necessarily reduced.
5.0	***Very high enrichment.*** State of peak macrofauna abundance.	LF	Very high numbers of one or two opportunistic species (i.e. capitellid worms, nematodes). Richness very low. Major sediment chemistry changes (hypoxia, moderate oxygen stress). Bacterial mat usually evident. Out-gassing occurs on disturbance of sediments.
		HF	Abundances of opportunistic species can be extreme (10 × LF ES 5.0 densities). Diversity usually significantly reduced, but moderate richness can be maintained. Sediment organic content usually slightly elevated. Bacterial mat formation and out-gassing possible.
6.0	***Excessive enrichment.*** Transitional stage between peak abundance and azoic (devoid of any organisms).	LF	Richness and diversity very low. Abundances of opportunistic species severely reduced from peak, but not azoic. Total abundance low but can be comparable to reference stations. %OM can be very high (3–6 × reference).
		HF	Opportunistic species strongly dominate, with taxa richness and diversity substantially reduced. Total infauna abundance less than at stations further away from the farm. Elevated %OM and sulphide levels. Formation of bacterial mats and out-gassing likely.
7.0	***Severe enrichment.*** Anoxic and azoic; sediments no longer capable of supporting macrofauna with organics accumulating.	LF	None, or only trace numbers of infauna remain; some samples with no taxa. Spontaneous out-gassing; bacterial mats usually present but can be suppressed. %OM can be very high (3-6 × reference).
		HF	Not previously observed—but assumed similar to LF sites.

With reference to the North Arm area, the ES assessment is being applied as a baseline to measure and assess potential changes in seabed organic enrichment resulting from possible aquaculture development in the future. In this context, the ES score can be used to describe the organic loading at a site and as a tool for setting environmental quality standards (EQS). While initially developed for salmon farming in the Marlborough Sounds region (i.e. a different environmental system), the ES score has been successfully applied to benthic monitoring of aquaculture sites within Akaroa Harbour (Taylor and Elvines 2016; Johnston et al. 2017), Tasman and Golden bays (Newcombe and Berthelsen 2016; Newcombe 2017) and the Firth of Thames and inner Hauraki Gulf (Morrisey et al. 2016). The assimilative capacity of the seabed may vary both geographically and seasonally, particularly in relation to factors such as water temperature, with cold water holding more oxygen and possibly facilitating increased exchange with the seabed. Although water temperatures in the North Arm region are lower than in the Marlborough Sounds, the effect of water temperature on the performance of the ES score is believed to be minor. The presence of additional stressors (e.g. sedimentation, resuspension of fine sediments) may confound the ability to use the ES methodology as a 'catch-all' tool for assessing seabed effects. This constraint applies equally to traditional infauna-based indicators of benthic effects of marine farms, such as diversity indices. The advantage of the ES score over these indices is that it incorporates direct measures of enrichment and of chemical changes in the sediment, in addition to the response of the fauna (see Morrisey et al. 2016). Further information regarding the use of the ES score within the North Arm region is provided in Section 6.1.

4. RESULTS

4.1. Bathymetry

A bathymetric chart for the North Arm region is presented in Figure 6. Water depths within the majority of the region are between 30 to 40 m, with isolated shallower patch reefs present. Depths in excess of 40 m were recorded northwest of Chase Head, as well as in the southern portion of Big Ship Passage. The map is intended for visualisation purposes only as it includes some degree of interpolation.

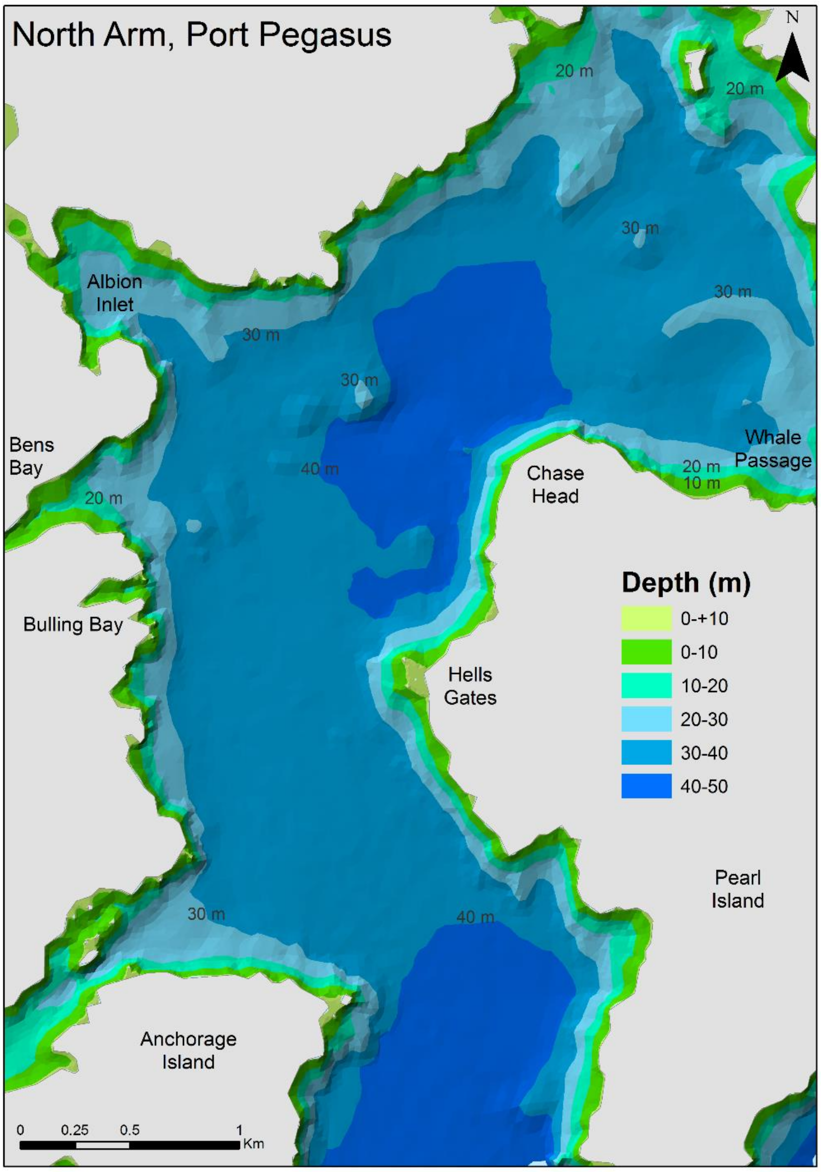

Figure 6. Bathymetry (in metres, relative to mean sea level) of North Arm, Port Pegasus/Pikihatiti. Based on Stage 1 (Elvines et al. 2016) and Stage 2 sonar imagery with additional LINZ data used where available. GPS positioning was accurate to ± 5 m.

4.2. Sonar imagery

Sonar mapping provided high-level detail of seafloor morphology and sediment characteristics within North Arm. Sonar data presented in Figure 7 denote backscatter information, with high-backscatter represented by light tones and low-backscatter by dark tones. In general, areas of high-backscatter (i.e. yellow areas) represent hard substrates, including areas of coarser-grained sediment and shell hash, while low-backscatter regions represent finer-grained sediments (e.g. mud and fine sand).

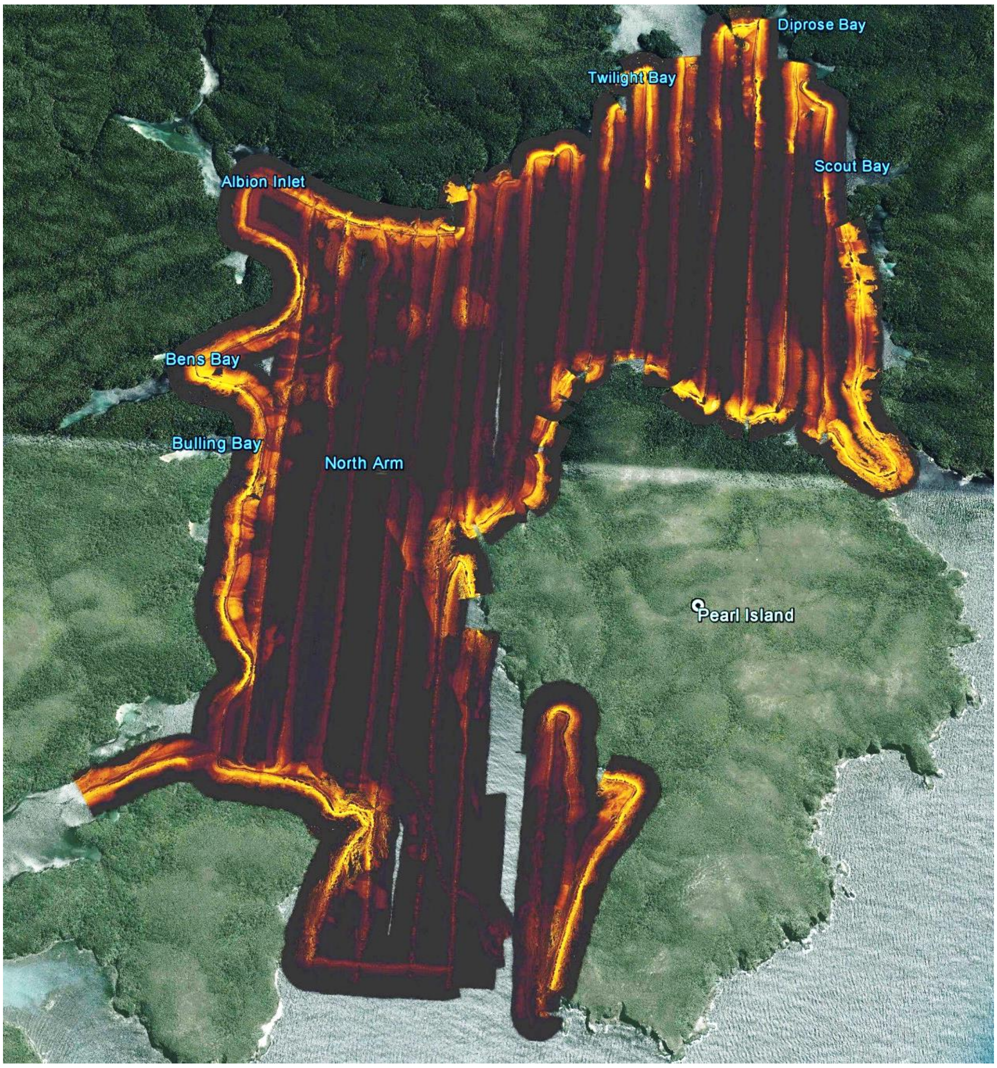

Figure 7. Sonar imagery used to delineate areas of hard substrate (e.g. reefs, cobble, shell hash, coarse sand) in North Arm, Port Pegasus/Pikihatiti.

A number of areas of hard substrate (e.g. reefs, cobble, shell hash, coarse sand) were subsequently identified (Figure 8). Rocky reef habitat was prevalent along the majority of the inner shoreline. Reef areas along the western edge of Pearl Island and the eastern edge of Anchorage Island were particularly pronounced, extending into Big

Ship Passage. In addition, several large rocky patch reefs were identified. The most significant of these extends c. 1.4 km out from the shoreline to the northeast from Bens Bay. Smaller isolated patch reefs were also located near to the entrance of Whale Passage and northwest and southwest of Chase Head. Coarse-grained sediment was prevalent at the entrance to Whale Passage and extended out towards the inner bay. Similar areas of coarse sediment were also present at the entrance to Albion Inlet.

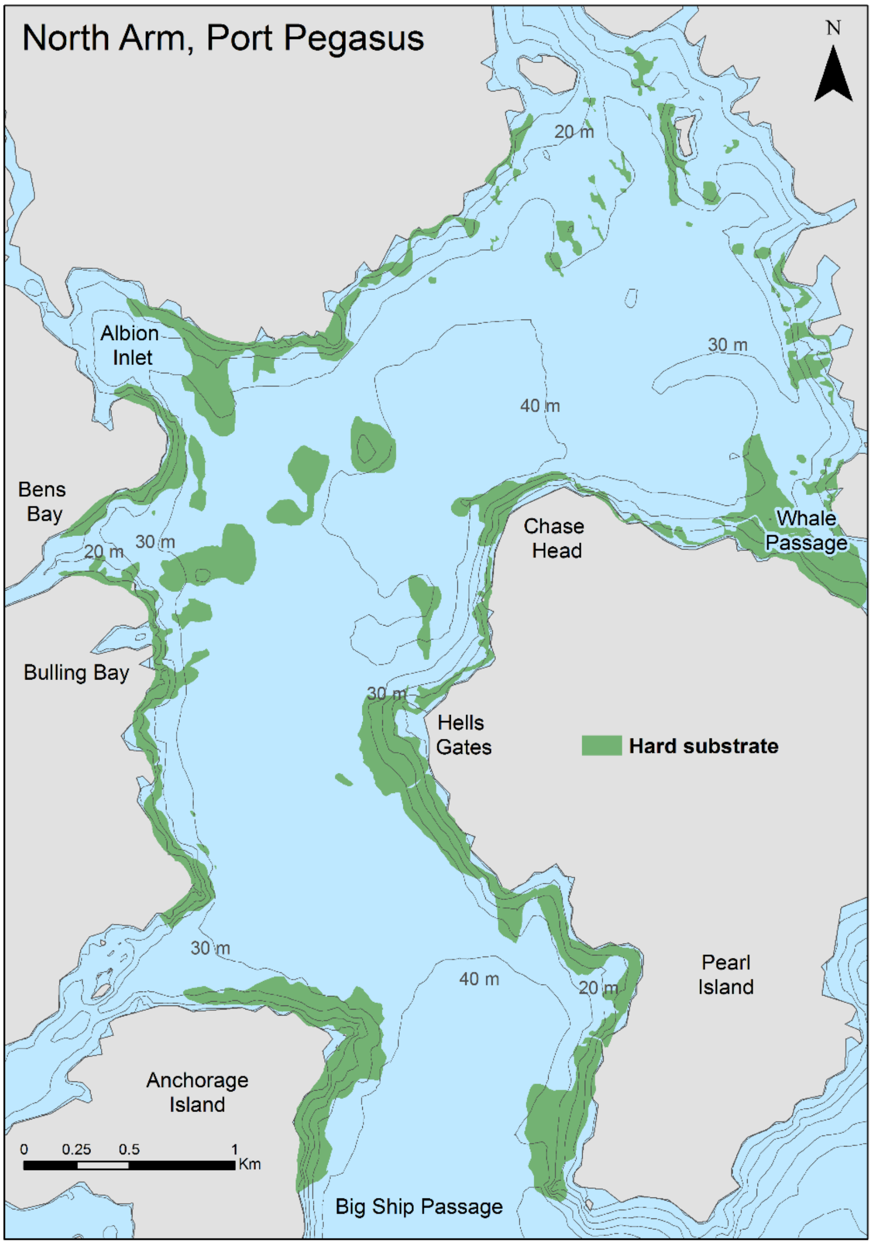

Figure 8. Areas of hard substrate (e.g. reefs, cobble, shell hash, coarse sand) within North Arm, Port Pegasus/Pikihatiti. Hard substrate areas were indicated by the presence of high backscatter within the sonar imagery data and are indicative only.

4.3. Benthic habitat visual assessments

Benthic habitats present within North Arm were classified into four substrate types: mud, sand, rocky reef/soft-sediment (i.e. patch reefs or boulder substrate with surrounding areas of mud or sand), and rocky reef (Figure 9). Classification of soft-sediment (i.e. mud and sand) substrates was sometimes hampered by clarity of the substrate images, however a consistent approach was applied. Results of high-level substrate groupings are presented for clarity in Figure 9. Further information on substrate type and texture are provided in Appendix 3. In general, mud substrates were prevalent to the north and northwest of Chase Head, in areas of increased water depth and lower wave energy. Sand substrates were extensive, ranging from fine rippled sand (e.g. Big Ship Passage) through to coarse sand and cobble habitat (e.g. entrance to Whale Passage). Rocky reef habitats were present in all shallow areas at the shoreline, and were particularly extensive along the western edge of Pearl Island. Patch reefs identified through sonar imagery were confirmed during drop-camera analysis (Figure 9).

Mud and sand substrates were characterised by relatively sparse epifaunal assemblages (Table 2). However, both were punctuated by occasional hard substrate (e.g. cobble, shell debris) with significantly increased epifaunal diversity. Brittle stars (mostly *Ophiopsammus maculata*), purple fanworms (*Branchiomma* sp.), sea cucumbers, sponges, brachiopods (likely *Neothyris lenticularis* and *Magasella sanguinea*), tube-dwelling anemones (*Cerianthus* sp.), black coral (order Antipatharia), sea pens (likely *Virgularia* sp.), and scallops (*Pecten novaezelandiae*) were observed on both substrate types. In addition, horse mussels (*Atrina zelandica*) and unidentified solitary ascidians were noted on mud substrates, and occasionally, sea stars on sand substrates. The coarse sand and cobble habitat near to the entrance to Whale Passage[3] was distinct from other sand substrates; the hard substrate provided by these features enabled a diverse range of sessile invertebrate species (sponges, ascidians, anemones, tubeworms) to colonise this area (Table 2). Scallops, brachiopods, dog cockles (*Tucetona laticostata*), flat oysters (*Ostrea chilensis*), horse mussels, brittle stars, sea cucumbers, eleven-armed sea stars (*Coscinasterias* sp.) and unidentified bivalves and gastropods were also observed.

Rocky reef habitats (includes areas of rocky reef with surrounding areas of soft-sediment) provided refuge for a range of epifaunal species and demersal fishes, and were characterised by many of the species present within the coarse sand and cobble habitat (Table 2). In addition, encrusting and turfing coralline algae and various kelp species (e.g. *Ecklonia*, *Carpophyllum*, *Macrocystis*, *Caulerpa*) were abundant, and kina (*Evechinus chloroticus*), cup sponges (*Cymbastela* sp.) and paua (*Haliotis* sp.) were observed occasionally. Reference images of the types of benthic habitats observed are provided in Figure 10.

[3] Primarily identified through GoPro footage taken during Stage 1 assessments (see Elvines et al. 2016).

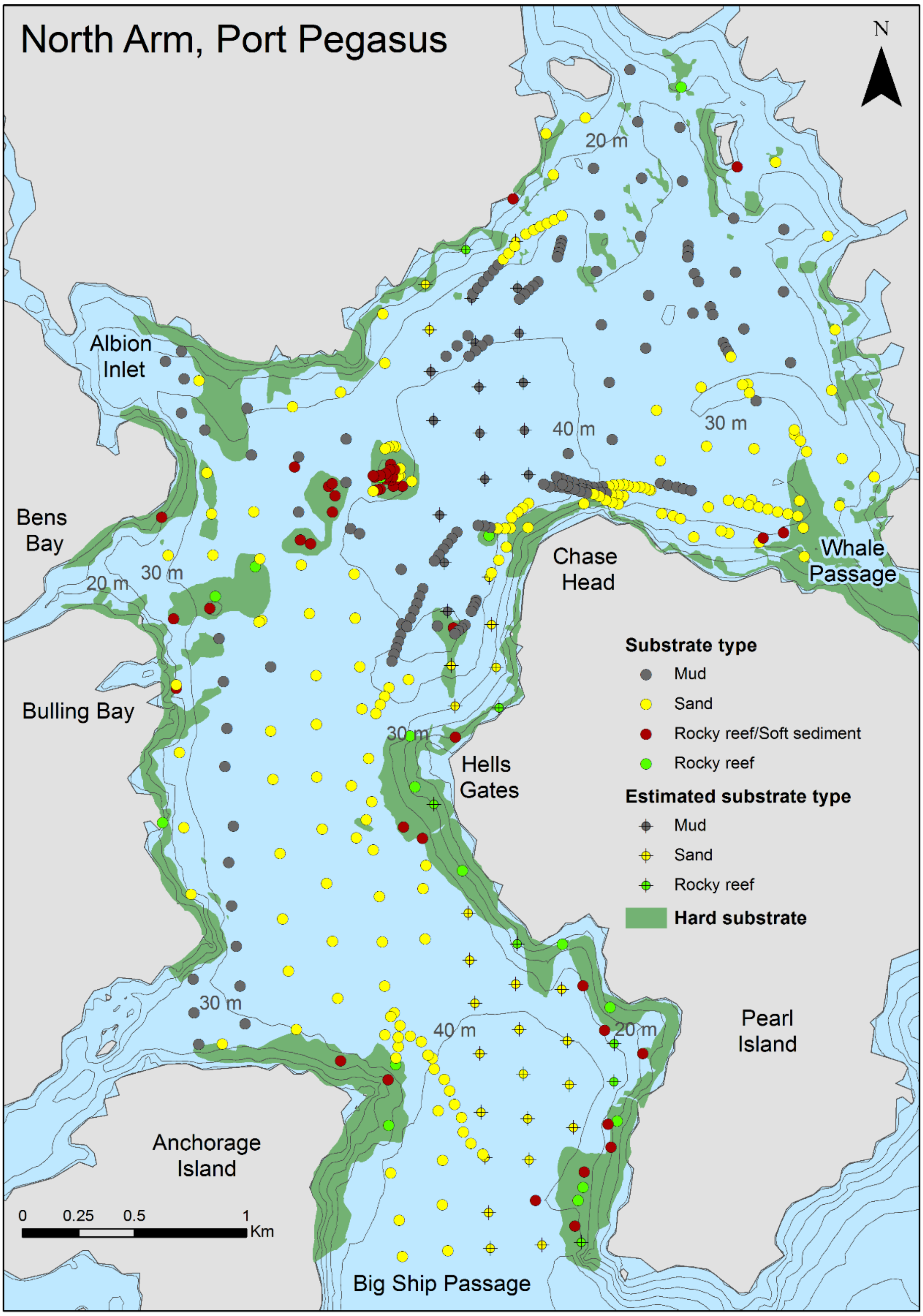

Figure 9. Seabed substrate type across North Arm, Port Pegasus/Pikihatiti. Estimated substrate types ae provided for sites where substrate classifications were assigned based on a combination of sonar imagery, nearby video footage and field notes.

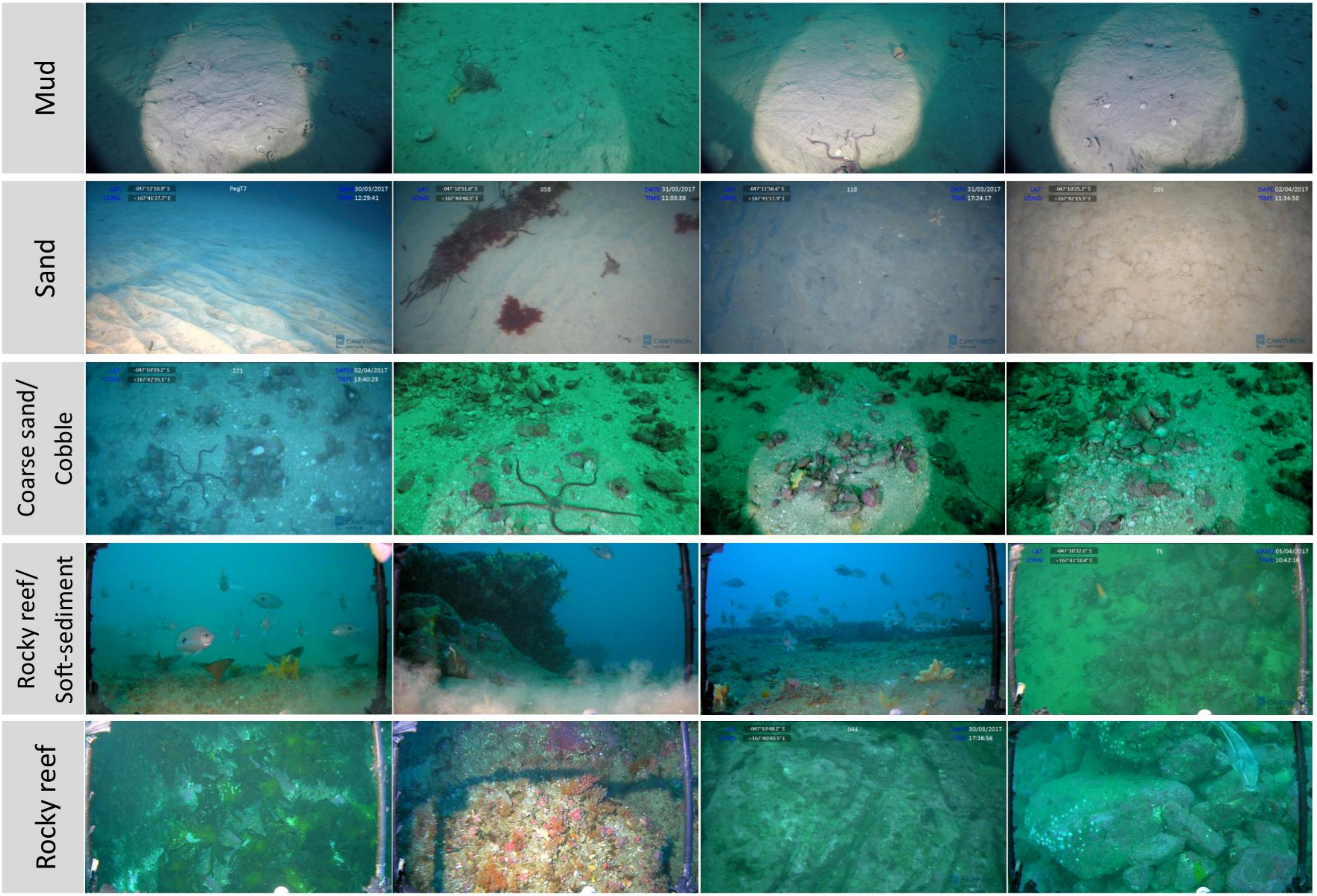

Figure 10. Reference images of high-level habitat types observed during drop-camera and video sled assessments within North Arm, Port Pegasus/Pikihatiti.

Table 2. Conspicuous epifauna and fish species observed in high-level habitats within North Arm, Port Pegasus/Pikihatiti.

Habitat type	Area	Depth range (m)	Conspicuous benthic biota	Fish species observed[4]
Mud	North and northwest of Chase Head, south-western shoreline (south of Albion Inlet to Pegasus Passage)	20 - 45	Brittle stars (mostly *Ophiopsammus maculata*), purple fanworms (*Branchiomma* sp.), sea cucumbers (various species), sponges, scallops (*Pecten novaezelandiae*), large calcareous tubeworms (various species), brachiopods (likely *Neothyris lenticularis* and *Magasella sanguinea*), horse mussels (*Atrina zelandica*), black corals, sea pens (*Virgularia* sp.)	Lemon sole (*Pelotretis flavilatus*), blue cod (*Parapercis colias*)
Sand	Big Ship Passage, northeast of Chase Head, shallow areas	6 - 44	Brittle stars (mostly *O. maculata*), diatom films, purple fanworms (*Branchiomma* sp.), sea cucumbers (various species), sponges, scallops (*P. novaezelandiae*), brachiopods (likely *N. lenticularis* and *M. sanguinea*), sea stars	Blue cod (*P. colias*), flounder (*Rhombosolea* sp.)
Coarse sand/ Cobble[5]	Entrance to Whale Passage, northeast of Pearl Island	15 - 25	Purple fanworms (*Branchiomma* sp.), tube-dwelling anemones (*Cerianthus* sp.), scallops (*P. novaezelandiae*), dog cockles (*Tucetona laticostata*), brachiopods (likely *N. lenticularis* and *M. sanguinea*), flat oysters (*Ostrea chilensis*), finger sponges, horse mussels (*A. zelandica*), brittle stars (mostly *O. maculata*), eleven-armed sea stars (*Coscinasterias* sp.), cushion stars (*Patiriella regularis*), bivalves, gastropods	Blue cod (*P. colias*), draught board shark (*Cephaloscyllium isabellum*), opal fish, triple fin (Tripterygiidae)
Rocky reef/soft-sediment	Northeast of Bens Bay, entrance to Albion Inlet, west and southwest of Chase Head, shallow areas along coastline	6 - 42	Cup sponges (*Cymbastela* sp.), finger sponges, small hydroids, small bryozoans, encrusting and turfing coralline algae, sea cucumbers (various species), kelp species (e.g. *Ecklonia*, *Carpophyllum*, *Macrocystis*, *Caulerpa*), ascidians, sea stars, kina (*Evechinus chloroticus*), paua (*Haliotis* sp.), anemones	Tarakihi (*Nemadactylus macropterus*), butterfly perch (*Caesioperca lepidoptera*), trumpeter (*Latris lineata*), scarlet wrasse (*Pseudolabrus miles*), blue cod (*P. colias*), blue moki (*Latridopsis ciliaris*), leather jacket (*Parika scaber*)
Rocky reef	West of Pearl Island, offshore from Anchorage Island, patch reefs	8 - 36	As specified for 'Rocky reef/soft-sediment' habitats. Areas of higher wave exposure (i.e. along the shoreline) generally had increased cover of kelp species (e.g. *Ecklonia*, *Carpophyllum*, *Macrocystis*, *Caulerpa*)	As specified for 'Rocky reef/soft-sediment' habitats

[4] Fish species were noted when observed on the video footage. However, as the survey method (i.e. drop-camera assessments) is not generally used for highly mobile species other taxa may have been present.
[5] Primarily identified through GoPro footage taken during Stage 1 assessments (see Elvines et al. 2016).

4.4. Taxa of ecological significance

Several taxa or groups of taxa were identified within the surveyed area that are of ecological significance and are known to be sensitive to anthropogenic impacts, including brachiopods, black coral, sea pens, tube-dwelling anemones and several large bivalve taxa (scallops, flat oysters, horse mussels and dog cockles). A description of each taxa or group, where they were found and associated densities is provided below. Reference images are provided in Figure 11 and Figure 12.

Brachiopods were observed in video footage across a range of habitats from mud to sand, as well as at the edge of patch reefs (Figure 13). Densities ranged considerably, with isolated individuals commonly observed. Large numbers of brachiopods were present on coarse sand and cobble substrates near Whale Passage. In addition, areas where brachiopods were moderately abundant[6] were observed surrounding Chase Head, adjacent to the patch reef off Bulling Bay and on the northern shoreline. Densities in these areas were noticeably less than that observed during preliminary scoping investigations of Paterson Inlet, where dense aggregations of individuals were common (Elvines et al. 2016; see Section 2.1). The most common brachiopods observed were large in size and pink-red in colour. Two species fitting this description (*Magasella sanguinea* and *Neothyris lenticularis*) are known to be common in the Stewart Island region.

Four individual black coral colonies (possibly *Antipathes fiordensis*) were observed on two video transects north of Chase Head (Figure 14). All black coral in the current survey were observed on soft-sediment substrates, although it is possible they were attached to isolated hard substrate (e.g. small rocks). Black coral have been recorded at this inner Pearl Island location previously[7], although in those instances all individuals were observed on subtidal rocky reef habitats (Grange 1990 and references therein; Laferriere 2017). Black coral have previously been recorded apparently free-living (i.e. unattached to rock) on muddy substrate in the northern section of North Arm (around Rosa Island) in 1989 and 2009 (pers. comm, D. Neale, Department of Conservation; Grange 1990 and references therein; Newman et al. 2009). The observations from the current survey, combined with previous studies, support the conclusion that black coral may inhabit soft-sediment environments in this location.

Sea pens (likely *Virgularia* sp.) were observed on mud substrates to the northeast of Chase Head (Figure 15). Densities ranged from sparse to moderate, with individuals observed restricted to a very localised distribution. Large tube-dwelling anemones (*Cerianthus* sp.) were also observed (Figure 16). Single individuals were most

[6] Qualitative density estimates applied: absent, not observed; sparse, isolated individuals; patchy, 2-3 individuals in close proximity; moderate, several individuals in close proximity; and abundant, dense aggregations (see Figure 12).

[7] A DOC survey in 2012 found 8 individual black coral on 4 of 6 transects assessed (Laferriere 2017).

commonly encountered, although densities were slightly higher on sandy substrate southwest of Chase Head. Isolated individuals were also observed near to the entrance to Whale Passage and on the eastern shoreline.

Several types of large bivalves were identified within the survey area (Figure 17). Scallops and flat oysters were both present, however they were noticeable in their sparseness. Of the areas surveyed in the current assessment, these taxa were largely restricted to coarse sand and cobble habitats near to the entrance of Whale Passage, on sandy substrates west of Chase Head, as well as along the northwest shoreline. Horse mussels were occasionally observed, with their distribution largely restricted to north of Chase Head and adjacent to the large patch reef off Bens Bay. Dog cockles (*Tucetona laticostata*) were occasionally observed protruding from the sediment within shell hash habitats. This taxa was primarily observed near to the entrance to Whale Passage and their abundance appeared to be relatively sparse. The current survey did not assess shallow areas within embayments and inlets present within North Arm; therefore, it is possible bivalve densities are higher in these areas.

In general, there was a distinct lack of three-dimensional biogenic structure across most of the soft-sediment habitats within North Arm. The sand substrate within Big Ship Passage is of particular note for the lack of epifauna, with large areas of distinct sand waves indicating sediments in this area are highly mobile. Large white calcareous tubeworms, sponges and colonial ascidians were observed sporadically on mud sediments, particularly in deeper areas. These taxa were generally attached to hard substrate such as cobble, shell debris or other epifauna such as horse mussels and tube worms.

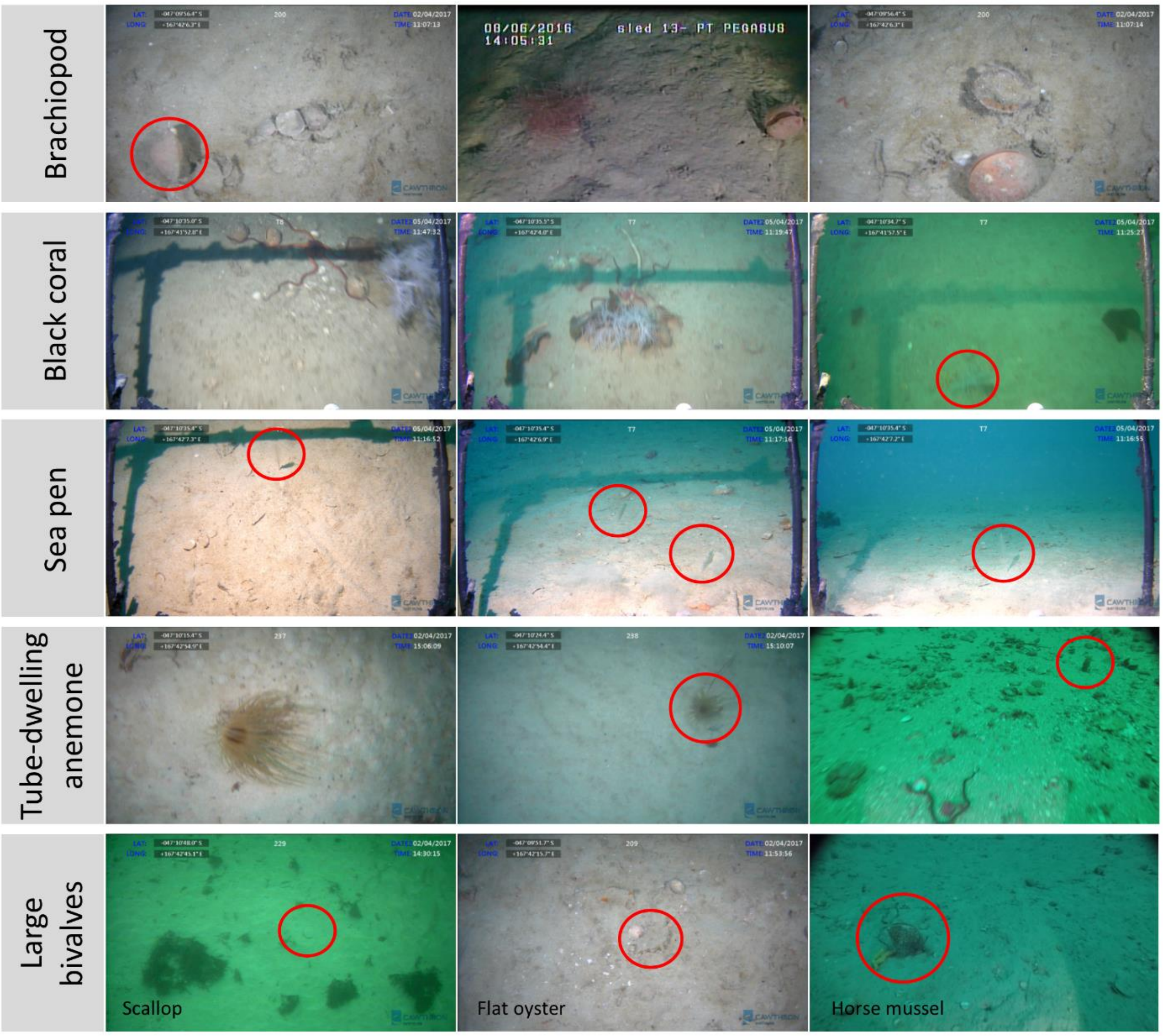

Figure 11. Reference images of selected taxa of ecological importance, including several large bivalve taxa (L-R: individual scallop, flat oyster and horse mussel), observed during drop-camera and video sled assessments within North Arm, Port Pegasus/Pikihatiti.

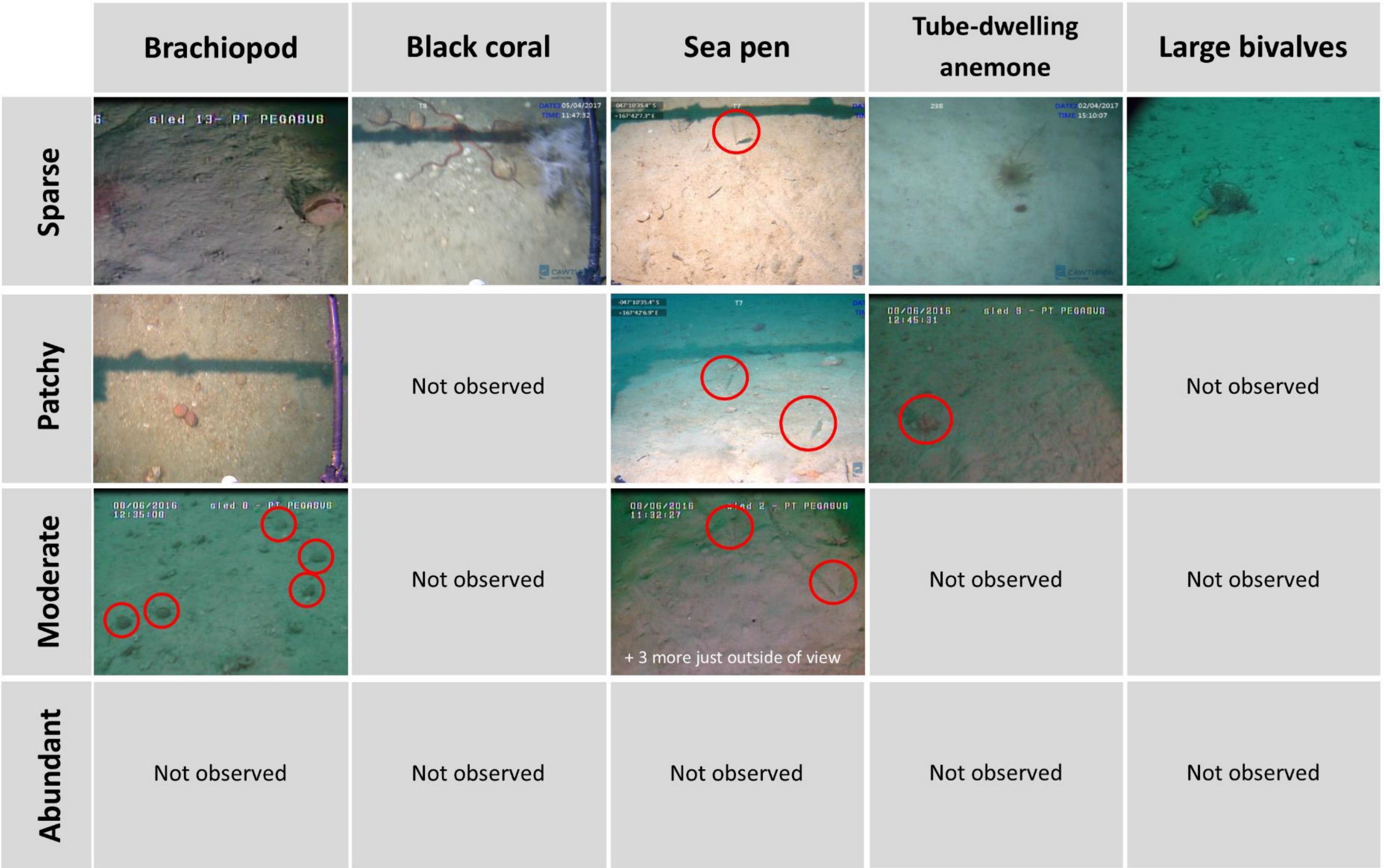

Figure 12. Reference images of qualitative density estimates applied: *absent*, not observed; *sparse*, isolated individuals; *patchy*, 2-3 individuals in close proximity; *moderate*, several individuals in close proximity; and *abundant*, dense aggregations.

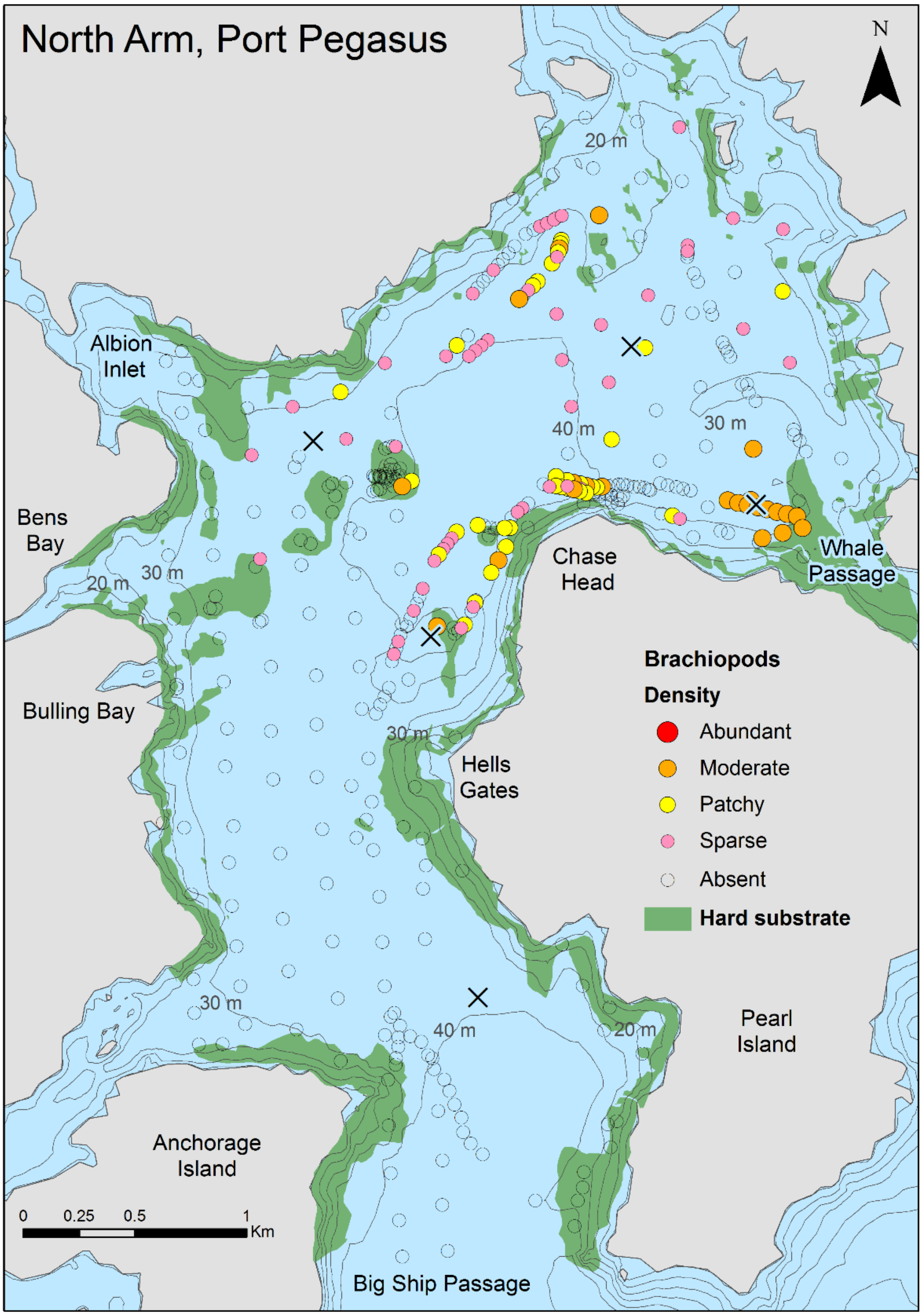

Figure 13. Brachiopod densities observed along drop-camera and video transects within North Arm, Port Pegasus/Pikihatiti. Qualitative density estimates applied: *absent*, not observed; *sparse*, isolated individuals; *patchy*, 2-3 individuals in close proximity; *moderate*, several individuals in close proximity; and *abundant*, dense aggregations. Brachiopod specimens were also identified from sediment cores (130 mm diameter, ~100 mm depth) at grab sampling sites 3, 9, 17, 23 and 40 (black crosses; see Section 4.5.2).

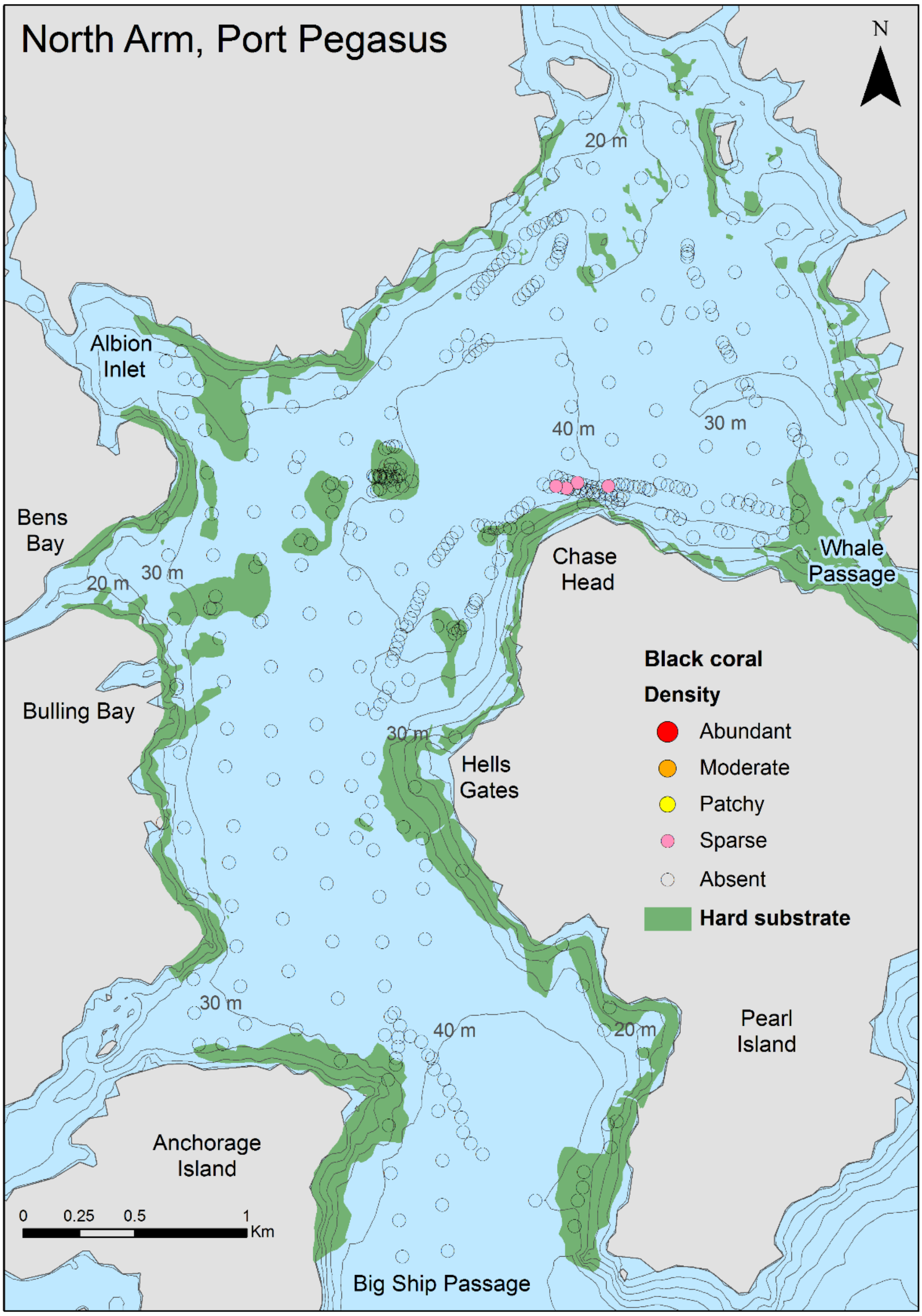

Figure 14. Black coral densities observed along drop-camera and video transects within North Arm, Port Pegasus/Pikihatiti. Qualitative density estimates applied: *absent*, not observed; *sparse*, isolated individuals; *patchy*, 2-3 individuals in close proximity; *moderate*, several individuals in close proximity; and *abundant*, dense aggregations.

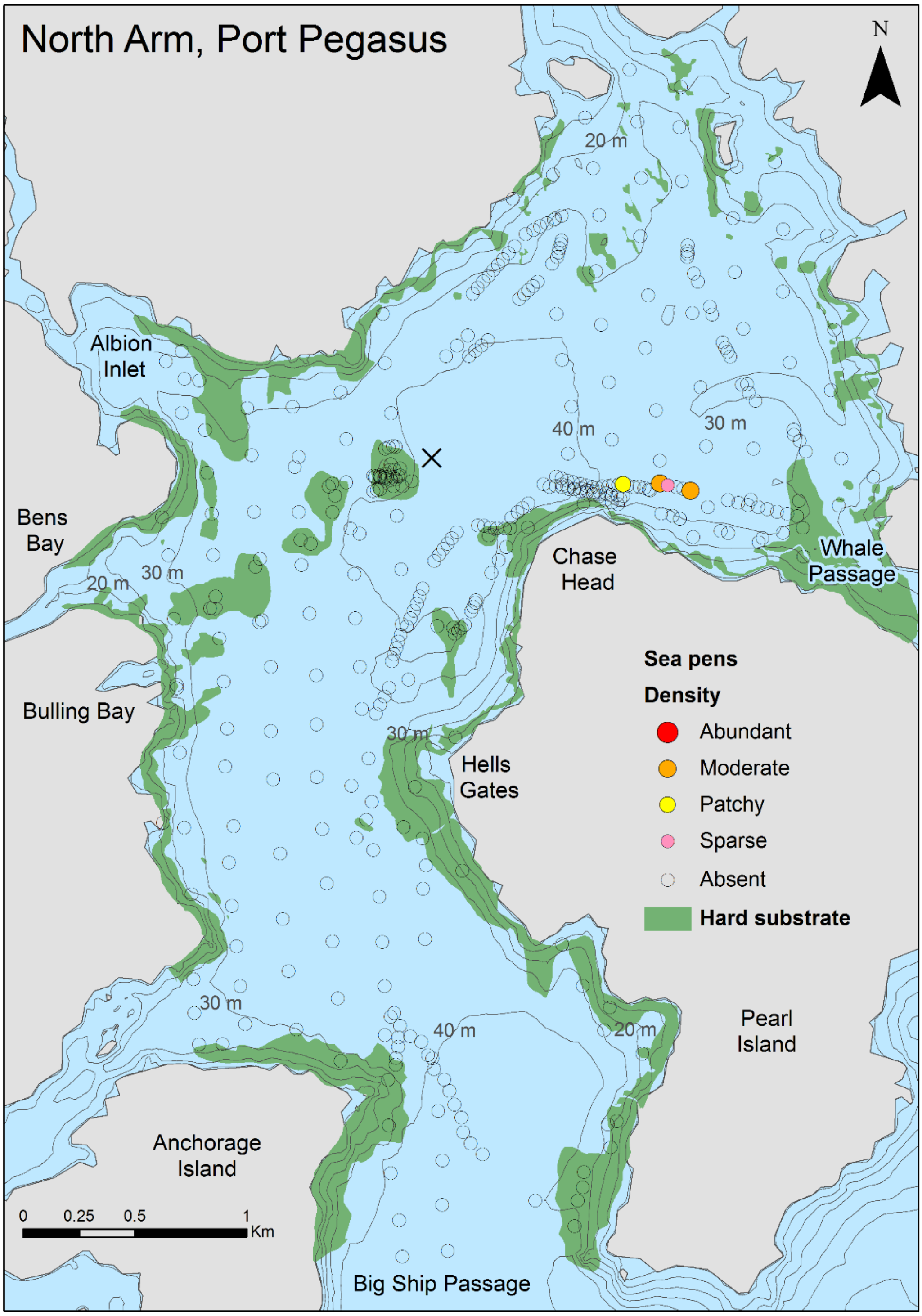

Figure 15. Sea pens (likely *Virgularia* sp.) densities observed along drop-camera and video transects within North Arm, Port Pegasus/Pikihatiti. Qualitative density estimates applied: *absent*, not observed; *sparse*, isolated individuals; *patchy*, 2-3 individuals in close proximity; *moderate*, several individuals in close proximity; and *abundant*, dense aggregations. Two individual sea pens were also identified from a sediment core (130 mm diameter, ~100 mm depth) at grab sampling site 10 (black cross; see Section 4.5.2).

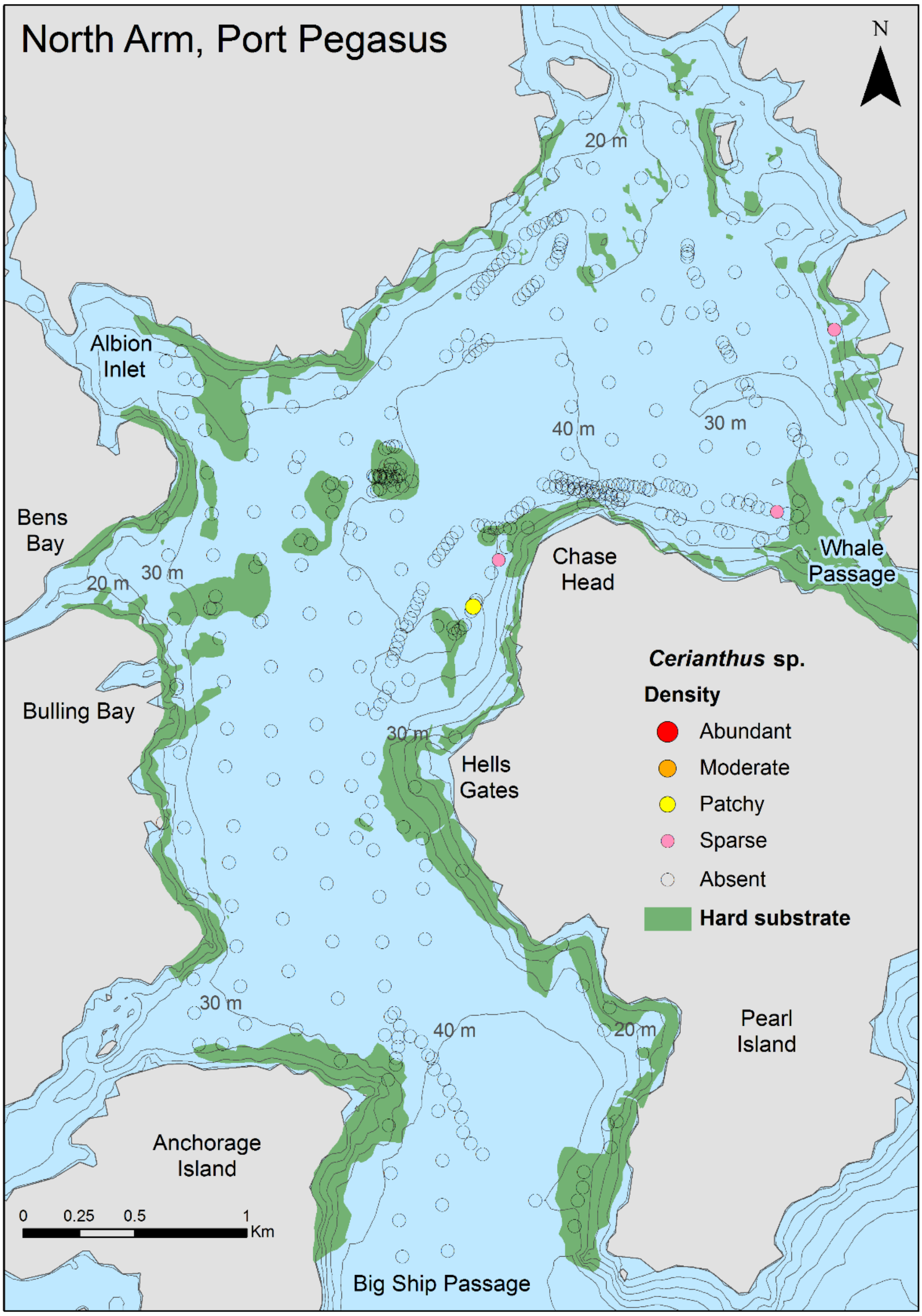

Figure 16. Tube-dwelling anemones (*Cerinathus* sp.) densities observed along drop-camera and video transects within North Arm, Port Pegasus/Pikihatiti. Qualitative density estimates applied: *absent*, not observed; *sparse*, isolated individuals; *patchy*, 2-3 individuals in close proximity; *moderate*, several individuals in close proximity; and *abundant*, dense aggregations.

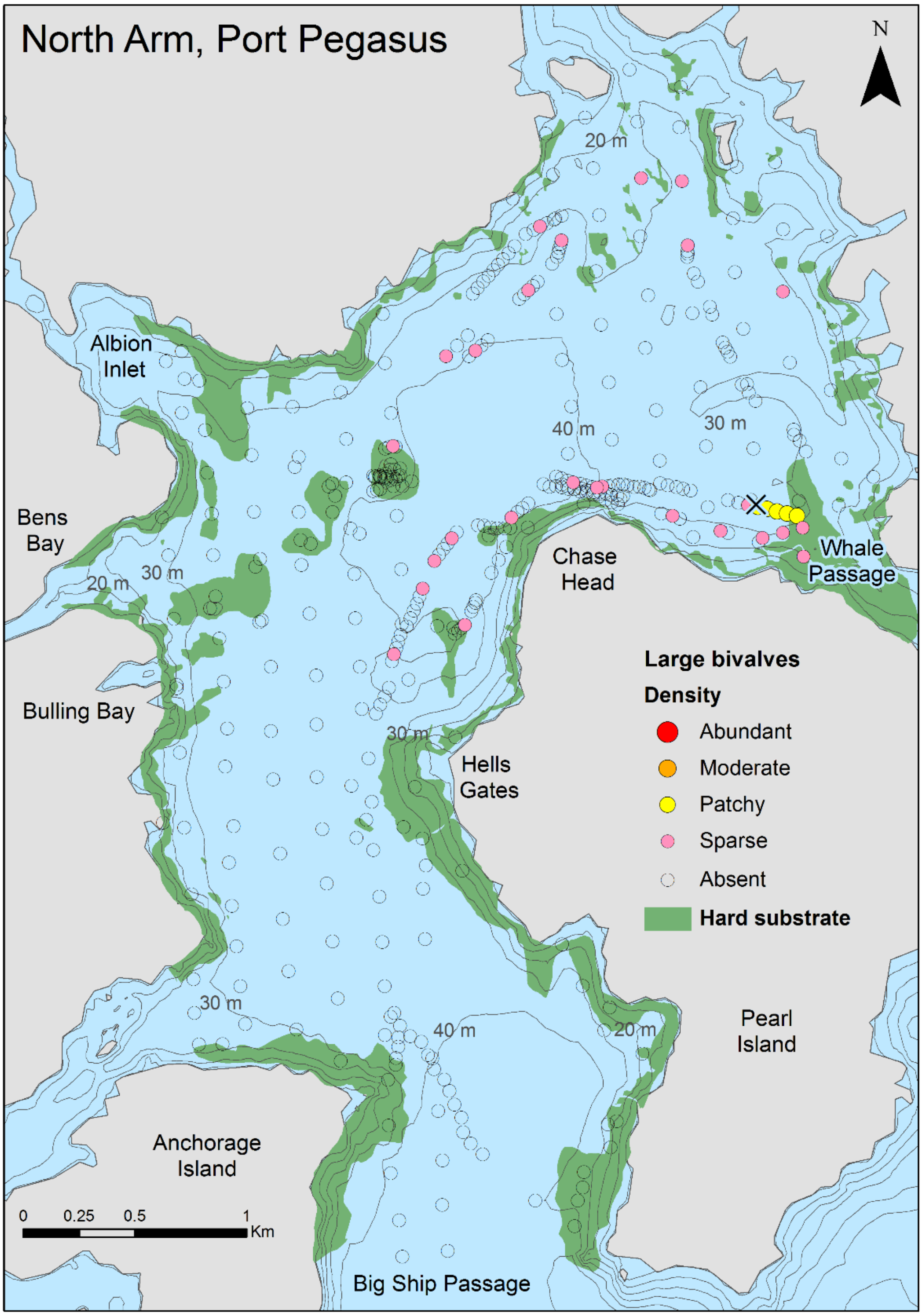

Figure 17. Densities of large bivalves (includes scallops, flat oysters, horse mussels and dog cockles) observed along drop-camera and video transects within North Arm, Port Pegasus/Pikihatiti. Qualitative density estimates applied: *absent*, not observed; *sparse*, isolated individuals; *patchy*, 2-3 individuals in close proximity; *moderate*, several individuals in close proximity; and *abundant*, dense aggregations. Two juvenile oysters and one juvenile scallop were also identified from a sediment core (130 mm diameter, ~100 mm depth) at grab sampling site 17 (black cross; see Section 4.5.2).

4.5. Physico-chemical properties and macrofaunal communities

4.5.1. Sediment grain-size distribution and organic content

Particle grain-size analysis indicated a separation of sediment types within the North Arm region (Figure 18), largely consistent with the results of visual assessments. Sites to the north of Hells Gates (sites 1–29) were generally characterised by muddy sand sediments, with sites also containing low proportions of gravel-sized (> 2 mm) particles (i.e. 'slightly gravelly muddy sand' and 'gravelly muddy sand'; Folk 1954). Exceptions include sites 6, 13 and 26 which all comprised sand sediments, and sites 17 and 28 which were found to comprise 'gravelly sand' sediments (9.3 and 11.5% gravel, respectively). Sites to the south of Hells Gates (i.e. within Big Ship Passage; sites 30-45) were generally characterised by sand sediments, again with some sites containing low proportions of gravel-sized particles (i.e. 'gravelly sand'; Folk 1954). Across the 45 sites, the proportion of sediments within the sand fraction ranged from 56.6 to 96.1%, followed by mud (2.3–43.1%) and gravel (< 0.1–11.5%) (Figure 19 and Figure 20).

The highest organic content was recorded north of Chase Head, at site number 3 (7.2% AFDW; Figure 21). Sites 6, 17, 28, 34 and 42 were notable for their relatively low organic content (2.2%, 1.9%, 2.5%, 1.9% and 1.0% AFDW, respectively). Full results of sediment grain-size fraction and organic content analyses are provided in Appendix 4.

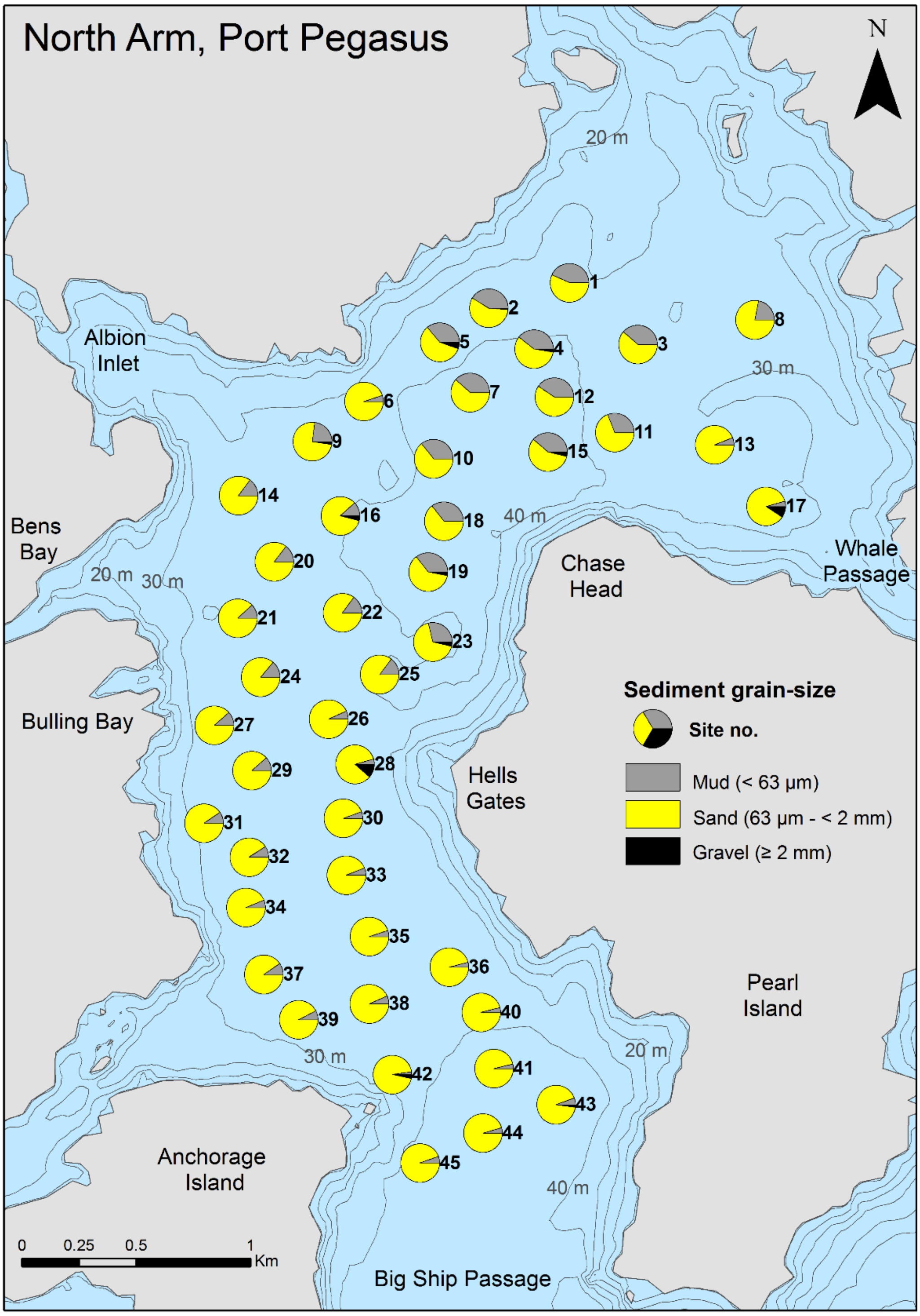

Figure 18. Particle grain-size distributions of sediments within North Arm, Port Pegasus/Pikihatiti. Sand comprises 5 fractions: very fine sand (≥ 63 µm to < 125 µm); fine sand (≥ 125 µm to < 250 µm); medium sand (≥ 250 µm to < 500 µm); coarse sand (≥ 500 µm to < 1 mm); and very coarse sand (≥ 1 mm to < 2 mm).

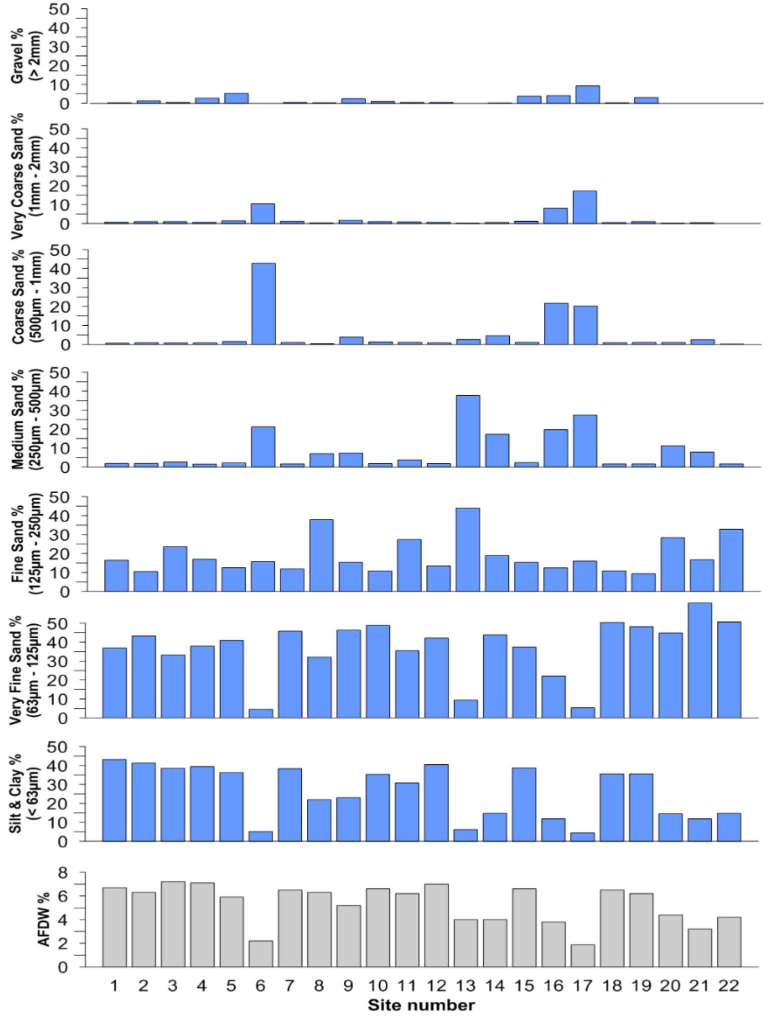

Figure 19. Sediment grain-size distribution (%) and organic content (% AFDW) for North Arm benthic sample sites 1-22.

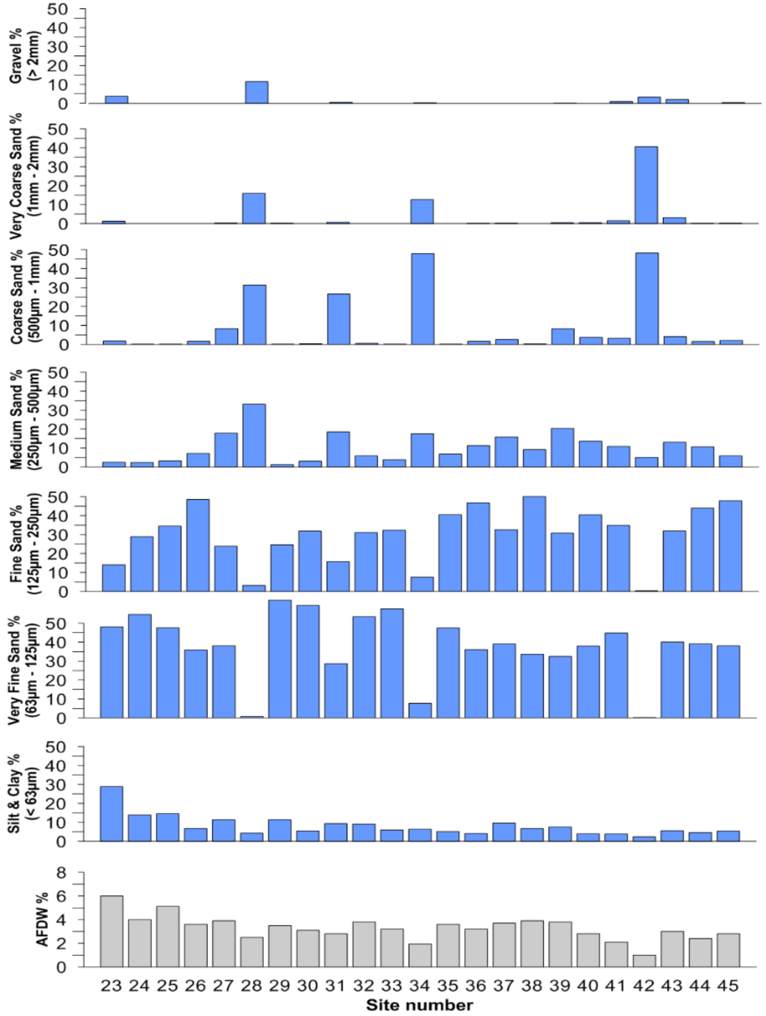

Figure 20. Sediment grain-size distribution (%) and organic content (% AFDW) for North Arm benthic sample sites 23-45.

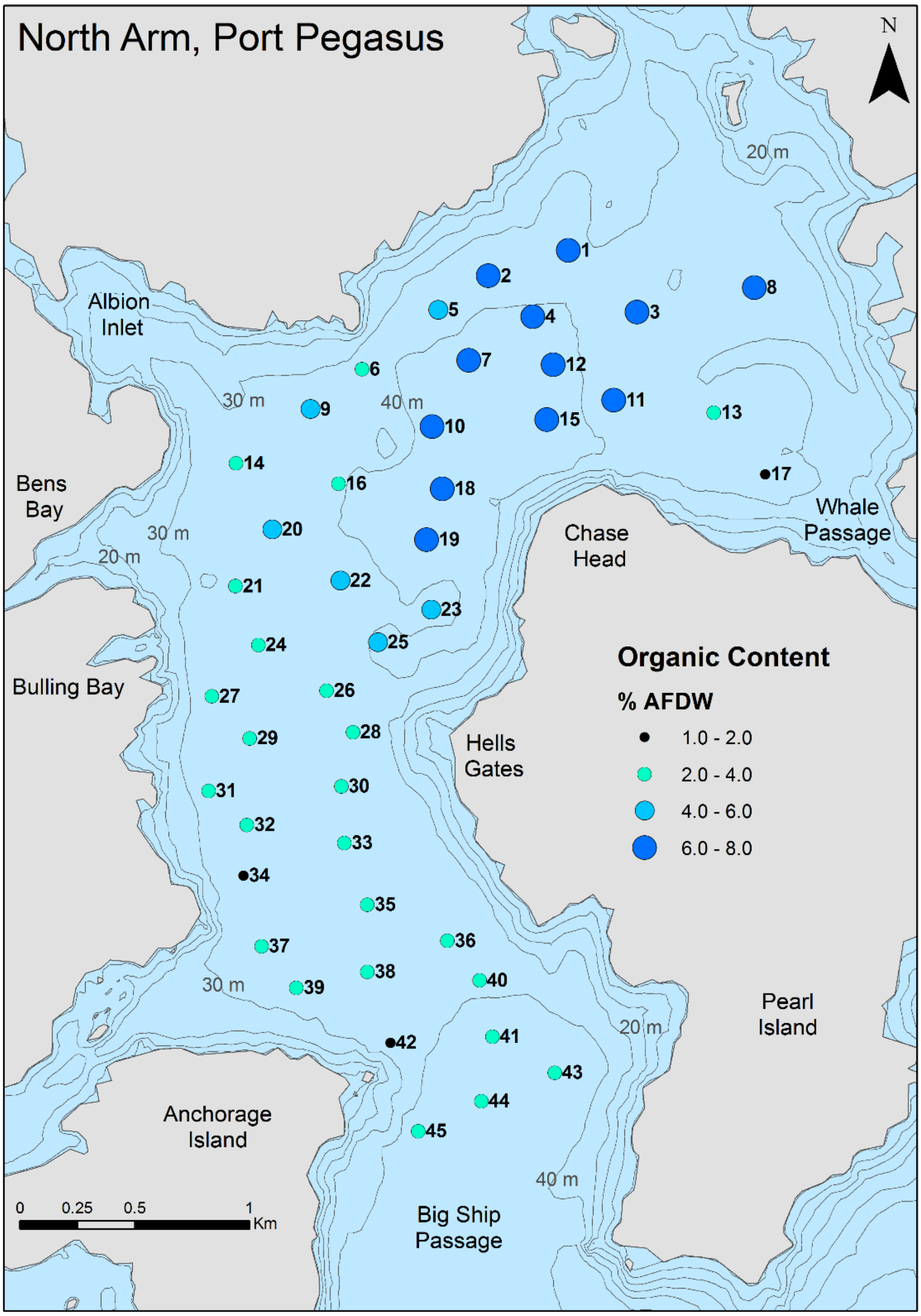

Figure 21. Total organic content (% ash-free dry weight; AFDW) of sediments sampled across North Arm, Port Pegasus/Pikihatiti.

4.5.2. Macrofauna

A total of 6,592 individual specimens, representing 133 different taxa, were observed within the 45 sediment samples collected throughout the North Arm region. The most abundant organism were nematodes (1,520 individuals), which were present in every sample except those from sites 38 and 40. High numbers of polychaete worms were also recorded (56 taxa identified); in particular, those from the families Cirratulidae and Syllidae (622 and 478 individuals, respectively). Total abundance across the 45 sites ranged from 34–468 individuals per core. In general, total abundance was higher in northern sites, particularly within muddier sites towards the middle of the bay (sites 1–2, 7, 9–10, 14–18 and 23; Figure 22). Two sites near to Albion Inlet (sites 9 and 16) had particularly high total abundance (428 and 468 individuals per core, respectively) reflecting increased numbers of polychaete worms and nematodes. Species richness (number of different taxa) ranged from 11–62 taxa per core and was largely consistent across the 45 sites (Figure 23). An exception was the site closest to the entrance to Whale Passage (site 17), which had species richness almost double that of the majority of other samples (62 taxa). The two sites near to Albion Inlet (sites 9 and 16) also had relatively high taxa richness recorded (40 taxa) as well as the highest total abundance.

Sediments had a high diversity of bivalve taxa (27 taxa identified), with several species of mussel (e.g. *Aulacomya maoriana, Modiolus areolatus*, *Musculus impactus*) identified, as well as juvenile oysters and scallops. Species diversity was also dominated by crustaceans including amphipods, shrimps, crabs and sea slaters. Notable epifaunal taxa identified included two species of brachiopods: the large red brachiopod *Magasella sanguinea* (1 specimen, site 17), and the small ribbed brachiopod *Notosaria nigricans* (1 specimen, site 17). Single unidentified juvenile brachiopods were also present within macrofauna communities at five additional sites, including one southern site within Big Ship Passage (sites 3, 9, 17, 23 and 40). Two individual sea pens (*Virgularia gracillima*) were identified at site 10, which was located in the greatest water depth across North Arm (c. 43 m depth). Other epifauna of note included the mud flat anemone (*Anthopleura aureoradiata*; 1 specimen, site 2), unidentified sponges (2 specimens, sites 9 and 17), and unidentified ascidians (15 specimens, sites 9, 17, 23 and 42).

Taxa were grouped to phylum level and ranked by relative abundance across the 45 benthic grab sites. The distributions of the seven most abundant phylum are presented in Figure 24 and Figure 25. A clear separation of substrate types is evident; muddier sites to the north have a higher proportion of annelids (i.e. worms) and nematodes, while sandy sites to the south have a higher proportion of arthropods (i.e. amphipods, crabs, isopods, cumaceans). A full taxa list and calculated indices are provided in Appendix 5 and Appendix 6, respectively.

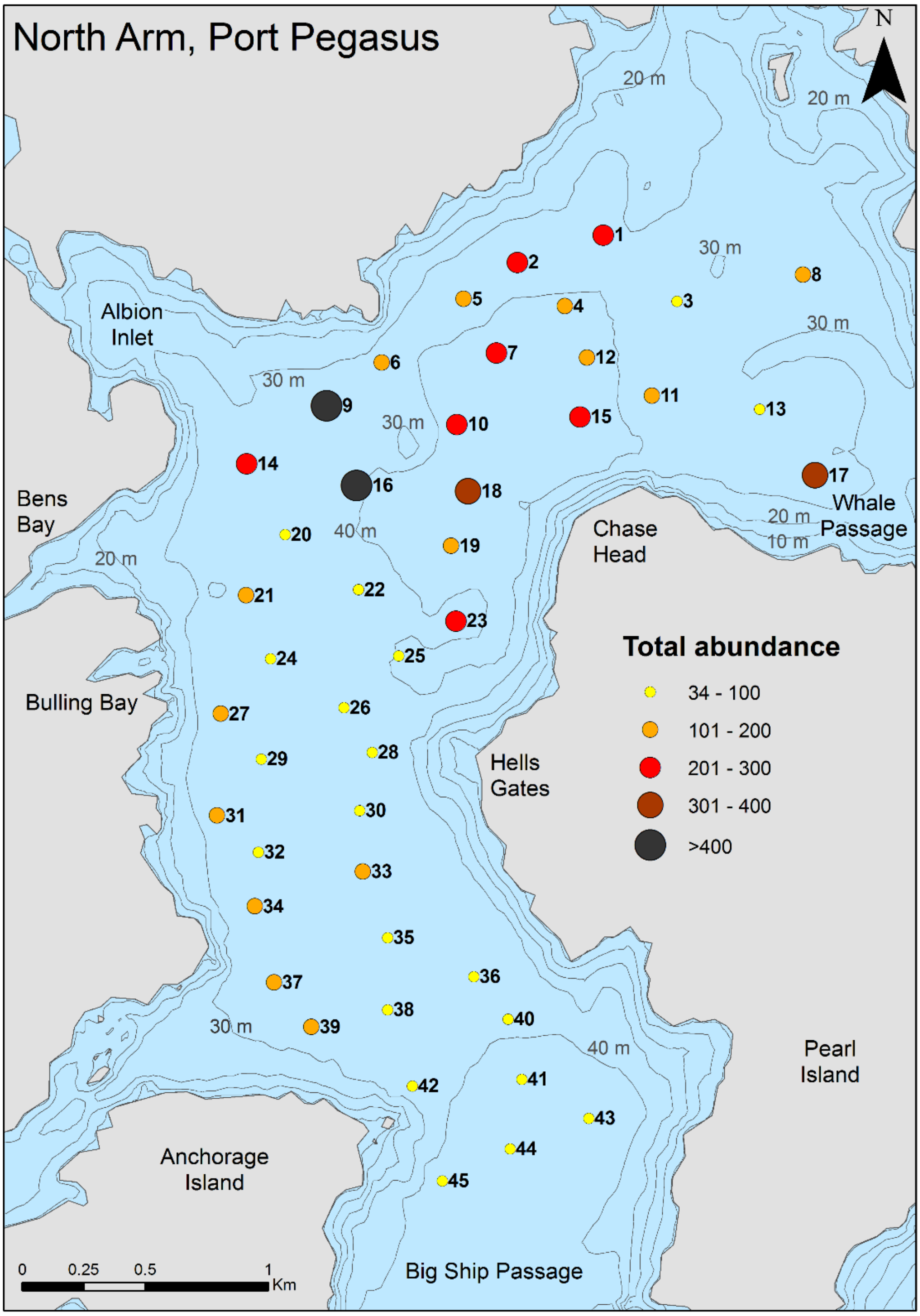

Figure 22. Macrofauna abundance per sediment core (130 mm diameter, ~100 mm deep) sampled across North Arm, Port Pegasus/Pikihatiti.

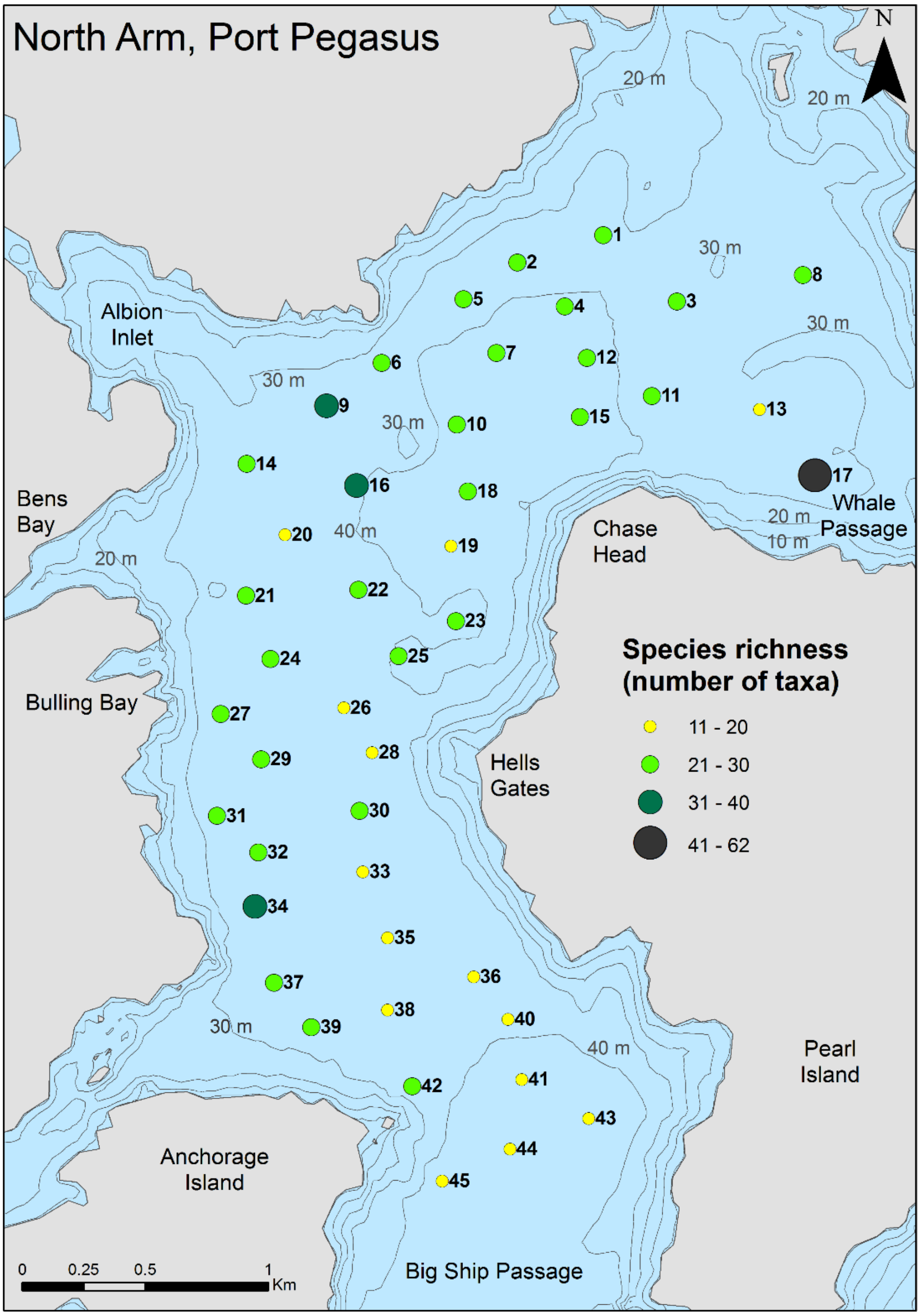

Figure 23. Macrofauna richness (number of taxa) per sediment core (130 mm diameter, ~100 mm deep) sampled across North Arm, Port Pegasus/Pikihatiti.

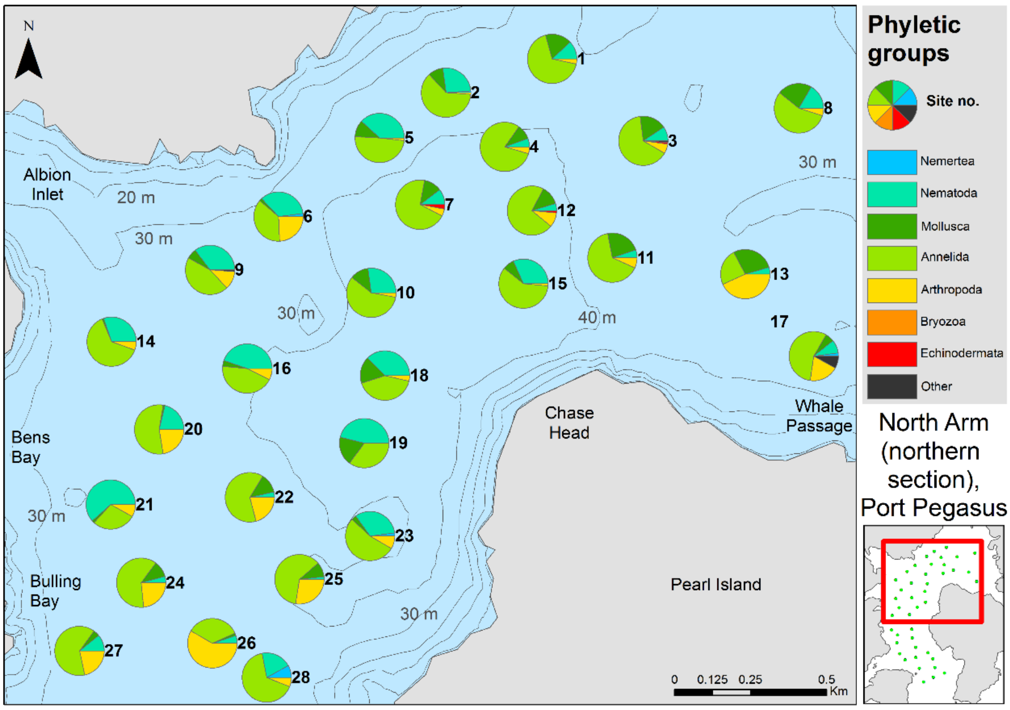

Figure 24. Macrofauna abundance (grouped by phylum) for the northern benthic grab sites in Port Pegasus/Pikihatiti. Only the most abundant phylum groups by number are presented for clarity. ‘Other’ includes: Porifera, Cnidaria, Platyhelminthes, Sipuncula, Brachiopoda, Hemichordata and Chordata.

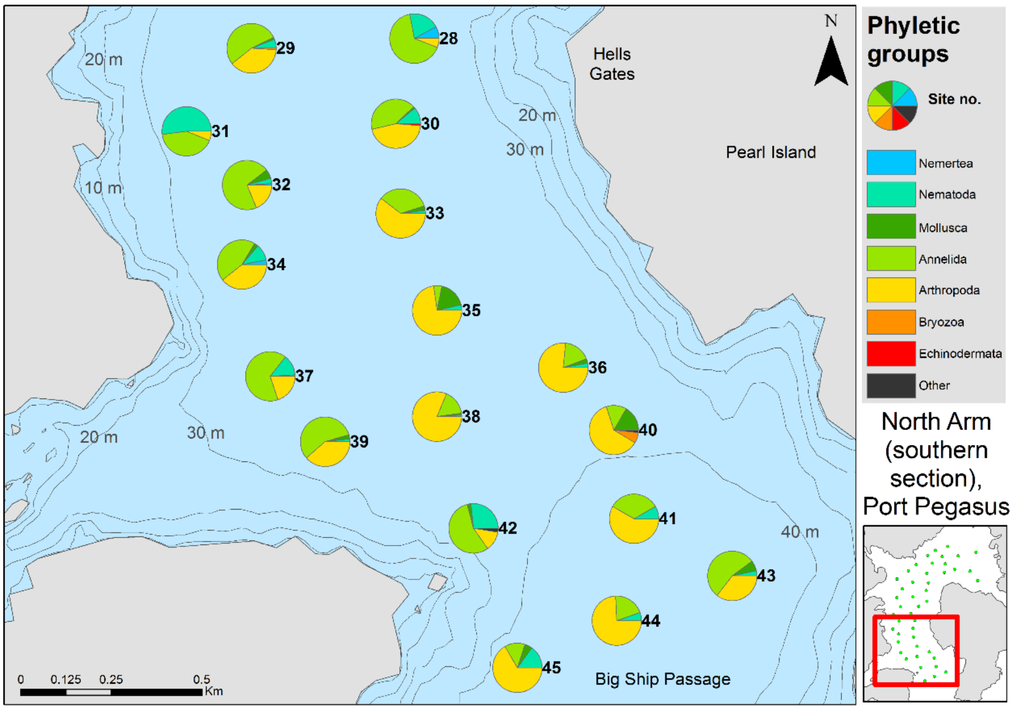

Figure 25. Macrofauna abundance (grouped by phylum) for the southern benthic grab sites in Port Pegasus/Pikihatiti. Only the most abundant phylum groups by number are presented for clarity. ‘Other’ includes: Porifera, Cnidaria, Platyhelminthes, Sipuncula, Brachiopoda, Hemichordata and Chordata.

A non-metric MDS plot based on the average abundance of benthic macrofauna revealed three well-defined groupings at 40% similarity (Figure 26). The site closest to the entrance to Whale Passage (site 17) was distinct from all other samples analysed. Eighteen taxa identified across all samples were present only at this site. The two remaining groups largely reflect differences in sediment types within North Arm. Sites with higher proportions of sand particles (i.e. southerly sites through Big Ship Passage and those closest to Whale Passage and Albion Inlet) were characterised by high numbers of cumaceans (hooded shrimps), amphipods (both unidentified and those from the family Haustoriidae), polychaete worms (*Prionospio* sp. and those from the family Cirratulidae) and nematodes. Sites with higher proportions of mud particles (i.e. sites in the deepest water, northwest of Pearl Island) were characterised by high numbers of nematodes, polychaete worms from the families Cirratulidae, Syllidae, Paraonidae, Maldanidae, and Dorvilleidae, as well as unidentified amphipods (see Appendix 7).

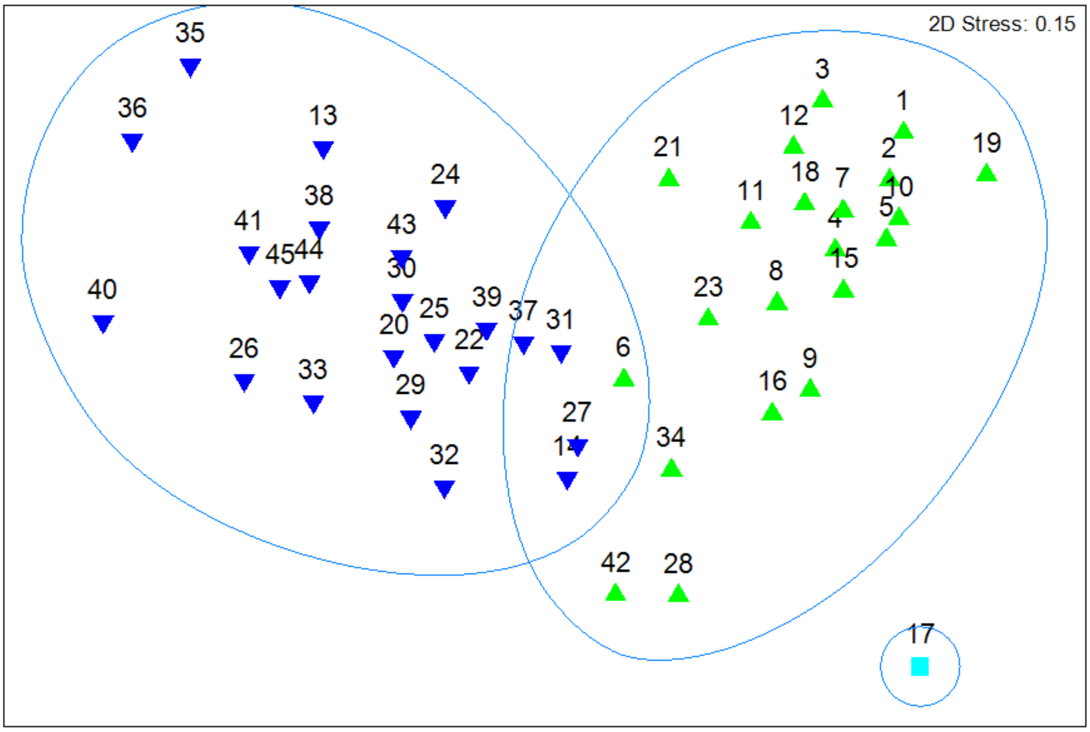

Figure 26. Non-metric multi-dimensional scaling (nMDS) plot of macrofauna abundance data from North Arm benthic grab sites showing similarity of samples at 40 percent (blue lines). Abundance data were fourth-root transformed. Resemblance based on Bray-Curtis similarities.

4.6. Assessment of seabed enrichment

Enrichment Stage (ES) scores varied from ES 1.62–2.41 over the North Arm region, reflecting natural conditions in the range of low-to-minor enrichment. In general, ES scores were slightly higher in the muddier sediments north of Hells Gates (ES > 2, minor enrichment). It is important to recognise that although ES 1 represents the pristine, natural end of the spectrum, in many situations the seabed can be naturally enriched and/or disturbed (MPI 2015). For example, in the Marlborough Sounds region much of the seabed is ES 2–2.5, but still reflects natural conditions. The low-level enrichment apparent at some sites in North Arm is likely to reflect natural enrichment, possibly due to the close proximity to riverine inputs; for instance from the creeks feeding Bell Topper Falls. Information on ES score calculation for the 45 grab sites is provided in Appendix 8.

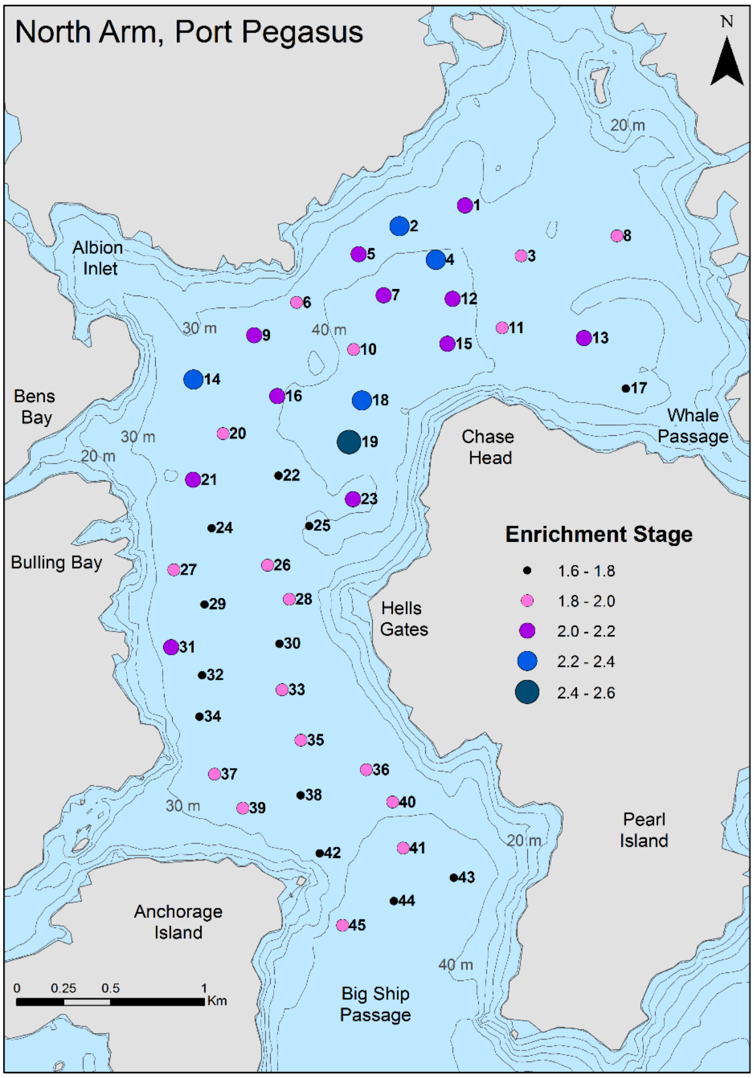

Figure 27. Enrichment Stage (ES) score at benthic sampling sites across North Arm, Port Pegasus/Pikihatiti (April 2017).

5. PREDICTED BENTHIC EFFECTS FROM PROPOSED FARMING SCENARIOS

5.1. Overview of benthic effects from finfish farming

Finfish farms are generally sited above soft-sediment habitats, rather than over rocky reef habitats. As such, research on farm-related seabed effects has focussed primarily on physico-chemical and ecological changes in these habitats. The dominant effect on the seabed arises from the deposition of faeces and uneaten feed, which leads to over-enrichment due to the high organic content of these biodeposits. Microbial decay of this material can dramatically alter the chemistry and ecology of the seafloor and the composition of the associated invertebrate communities (e.g. Keeley et al. 2012a).

Research both within New Zealand and overseas has consistently shown that excess feed and faecal deposition from finfish farms can change well-aerated and species-rich environments into hydrogen sulphide-dominated anoxic (oxygen-depleted) zones, or under worst-case conditions, into azoic sites (devoid of life). Anoxic zones are generally inhabited by only a few sediment-dwelling species tolerant of the degraded conditions (e.g. opportunistic polychaete species). Extremely enriched, hydrogen sulphide-dominated conditions can also have adverse health effects on fish and other fauna (Gowen and Bradbury 1987; Black et al. 1996).

The depositional 'footprint' of a typical finfish farm extends tens to hundreds of metres from the point of discharge depending on the strength of water current flows at the site (e.g. Keeley et al. 2013b). These footprints are often skewed in an elliptical pattern in the direction of prevailing currents. Farm-related enrichment effects tend to be most evident directly beneath the pens, and exhibit a strong gradient of decreasing impact with increasing distance from the net pens. Ecological effects of seabed enrichment stem from elevated rates of biodeposition, and accordingly, can be managed by monitoring the magnitude and spatial extent of the depositional footprint, and adjusting the amount of feed discharged.

5.2. Identification of potential areas suitable for finfish farming

5.2.1. Exclusion buffers

A coarse assessment of areas potentially suitable for finfish farming in the North Arm region was undertaken initially. Circular exclusion 'buffers' were placed around areas of hard substrate or coarse-grained sediments and areas containing potentially sensitive taxa, identified through sonar imagery and drop-camera transects (Figure 28). Buffers[8] with a 250 m radius were applied to large offshore rocky reef

[8] Given that no farm-related effects have been detected on reef sites in the Marlborough Sounds within 100 m of farms these buffers are potentially overly cautious. However, they were deemed necessary to account for the potential of wave-driven resuspension events to disperse farm sediments, and to provide further protection for sensitive taxa.

areas, the diverse benthic habitat near Whale Passage, and areas where black coral was found (i.e. to the north and northwest of Chase Head). In addition, buffers with a 150 m radius were applied to coastal reefs and small patch reefs. These exclusion zones were considered appropriate to mitigate risk of farm-related benthic biodeposition effects because: (i) Port Pegasus/Pikihatiti is a relatively low-flow environment, therefore, farm-related biodeposits are predicted to remain within 100 m of the net pens; and (ii) no farm-related effects to reef communities have been noted over ten years of monitoring in the Marlborough Sounds, despite reef monitoring sites being situated less than 100 m from salmon farms (see Dunmore 2017).

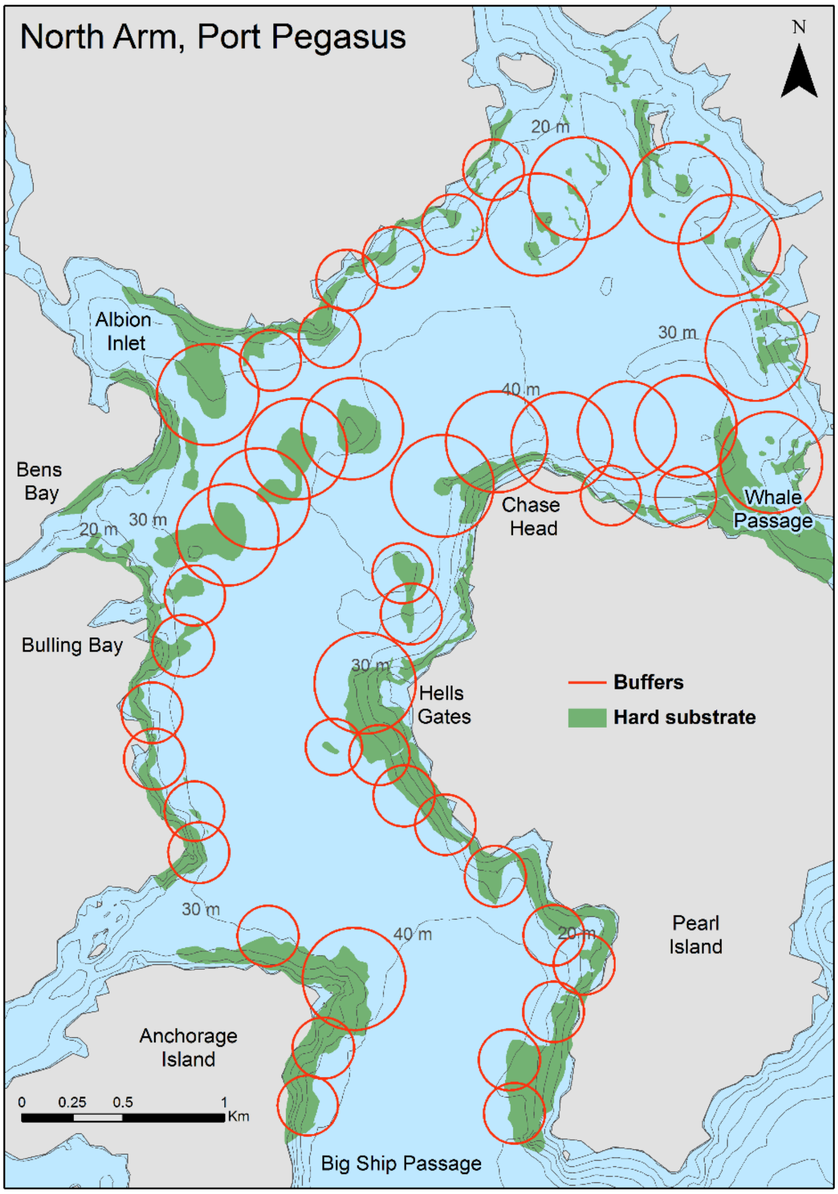

Figure 28. Exclusion buffers around hard substrate areas, including rocky reef habitats and areas of coarse-grained sediment near to Whale Passage. Areas of black coral (i.e. to the north and northwest of Chase Head) are also included.

5.2.2. Index of Suitable Location

The capacity of the environment to disperse and assimilate farm wastes is primarily a function of water depth and current speeds (e.g. Yokoyama et al. 2004, 2007). Water depth and current speeds affect the extent of particle dispersion; thus they are the primary attributes that modify both the magnitude and spatial extent of seabed effects at potential farm sites. Increased dispersion not only reduces localised sedimentation and accumulation of organic matter, but it also increases oxygen delivery to the sediments, thus allowing for more efficient mineralisation of farm wastes (Findlay and Watling 1997). Consequently, sites located in deep water (> 30 m) and exposed to strong water currents (> 10 $cm.s^{-1}$ on average) will have more widely dispersed depositional footprints with less intense enrichment than shallow, poorly flushed sites (Keeley et al. 2013a, 2013b).

To provide additional guidance on suitable locations for potential farm sites, the Index of Suitable Location (ISL) for finfish farming (as per Yokoyama et al. 2004) was calculated for the entire North Arm area. The ISL is expressed as:

$$ISL = DV^2,$$

where D is the water depth (m) at a fish farm site and V is the time-averaged current velocity ($m.s^{-1}$), based on preliminary hydrodynamic model outputs (a five-day model run). The ISL has been proposed as an effective indicator for assessment of the assimilative capacity and the upper limit of fish production at a given location (Yokoyama et al. 2004). Although application of this index for salmon farming is untested[9], it provides a good single metric of water depth and flow.

Findings based on the preliminary water current data suggest that the majority of North Arm has a very low ISL (Figure 29). The exception is Whale Passage and an area near the eastern entrance to Big Ship Passage; however, the biological features in these areas are such that they are not considered suitable locations for farming operations. Allowing for exclusion of buffer areas around areas of hard substrate, coarser-grained sediment and sensitive taxa, the ISL results indicate that mid-channel areas in Big Ship Passage have the greatest potential for farming (ISL = 0.2–0.3; Figure 29). The remaining area in North Arm has an ISL of < 0.1, suggesting potential production is limited and associated benthic effects would need to be carefully managed.

[9] The ISL was developed using data from a farming area in Japan that produces 15,000-20,000 metric tons of red sea bream (*Pagurus major*) and Japanese amberjack (*Seriola quinqueradiata*) per annum.

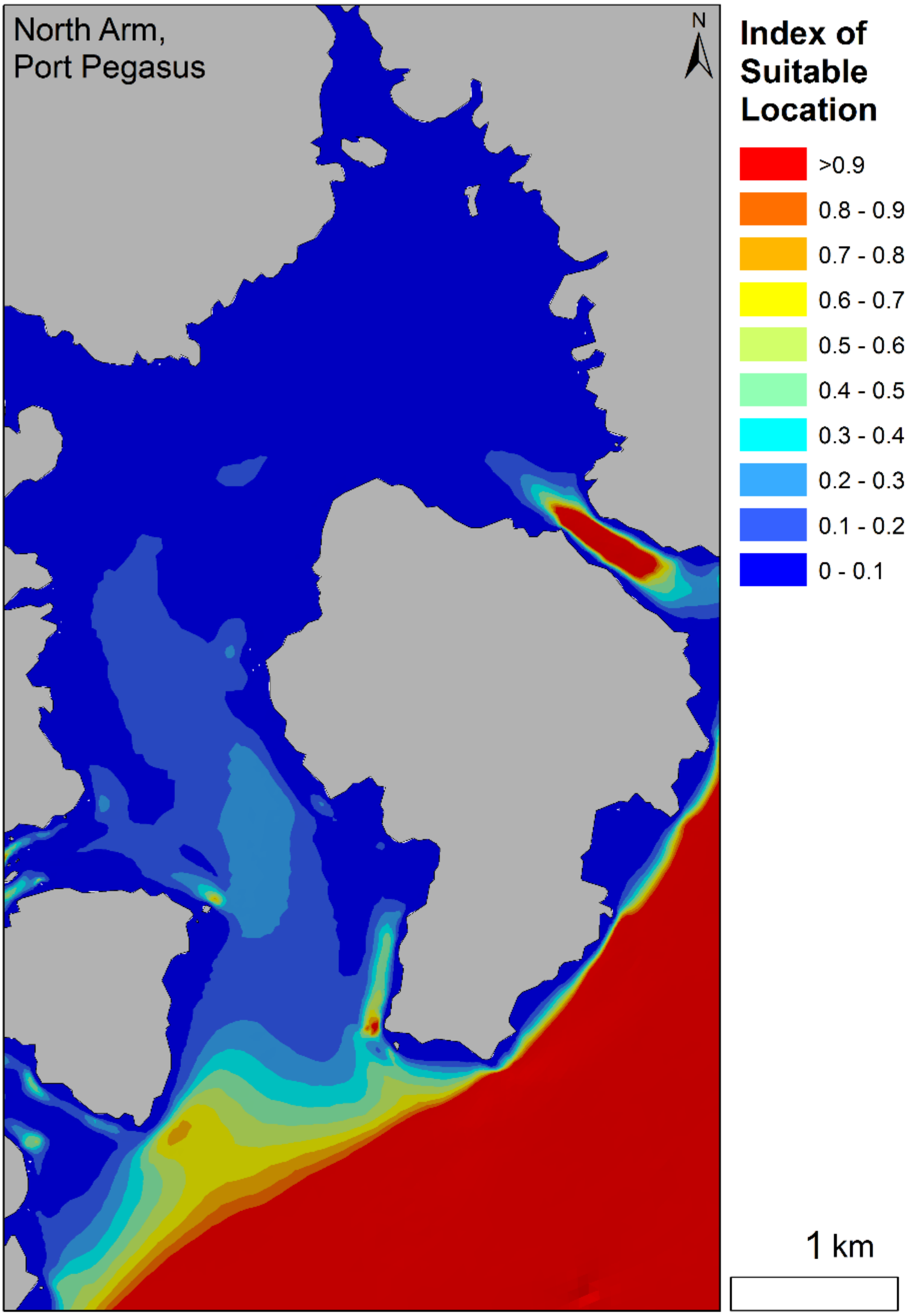

Figure 29. Index of Suitable Location (ISL), where an ISL > 0.1 equates to a greater potential for fish production with a lower probability of adverse benthic effects (based on water current and depth, Yokoyama et al. 2004).

5.3. Depositional modelling of finfish farm waste

Deposition of finfish farm waste (i.e. uneaten feed and faeces) is the primary driver of seabed impacts. To understand the dispersion of waste products from farm sites, a number of depositional models have been developed. These models combine physical properties of water currents with farm configuration and production parameters to predict the distribution and intensity of waste product deposition on benthic habitats (Cromey et al. 2002; Reid et al. 2009).

The depositional model DEPOMOD v 2.2 was applied to the current assessment of finfish aquaculture development within North Arm. DEPOMOD was selected from a number of analogous particle tracking models because it is widely used and published, and designed specifically for managing finfish farm wastes (Cromey and Black 2005; Cook et al. 2006; Magill et al. 2006). DEPOMOD is notable among fish farm impact models in that a number of the processes it simulates have been validated against field measurements (Cromey et al. 2002; Chamberlain and Stucchi 2007). Importantly, outputs from DEPOMOD have been validated for New Zealand conditions through comparison of the predicted depositional footprint and observed ecological responses at three existing salmon farms in the Marlborough Sounds region (Keeley et al. 2012a, 2013a, 2013b). For low-flow sites (average mid-water current velocities < 10 cm.s^{-1}) in the Marlborough Sounds, approximately 6 kg m^{-2} yr^{-1} was found to result in a highly enriched state (equivalent to ES 5) under a 'no resuspension scenario' (Keeley et al. 2013a, 2013b). For high-flow sites (average mid-water current velocities > 10 cm.s^{-1}), approximately 13 kg m^{-2} yr^{-1} of deposition was found to result in a highly enriched state (equivalent to ES 5). Under these ES 5-type conditions, infaunal communities approach peak abundance, but remain able to assimilate farm-related biodeposits (see ES descriptions, Table 1).

5.3.1. Proposed finfish farm locations within the North Arm region

Based on the results of the ISL analysis (Section 5.2), four areas (c. 10 ha each) within Big Ship Passage were identified as having the greatest potential for grow-out of salmon while minimising benthic effects (f1-f4; Figure 30). A smolt growing area (c. 1.3 ha) was also identified on the coastline north of Albion Inlet (s1; see Figure 30). This location was selected as it provided some separation from grow-out areas, a feature that was requested during discussions with industry (pers. comm. T. Foggo, Sanford Ltd). A maximum of 16 x 160 m circumference pens (two rows of eight pens, c. 20 m spacing between pens) was considered at each of the four potential farming areas. A maximum of 8 x 100 m circumference pens (two rows of four pens, c. 15 m spacing between pens) was considered for the smolt growing area. Refer to Appendix 9 for an explanation of farm site selection and production scenarios.

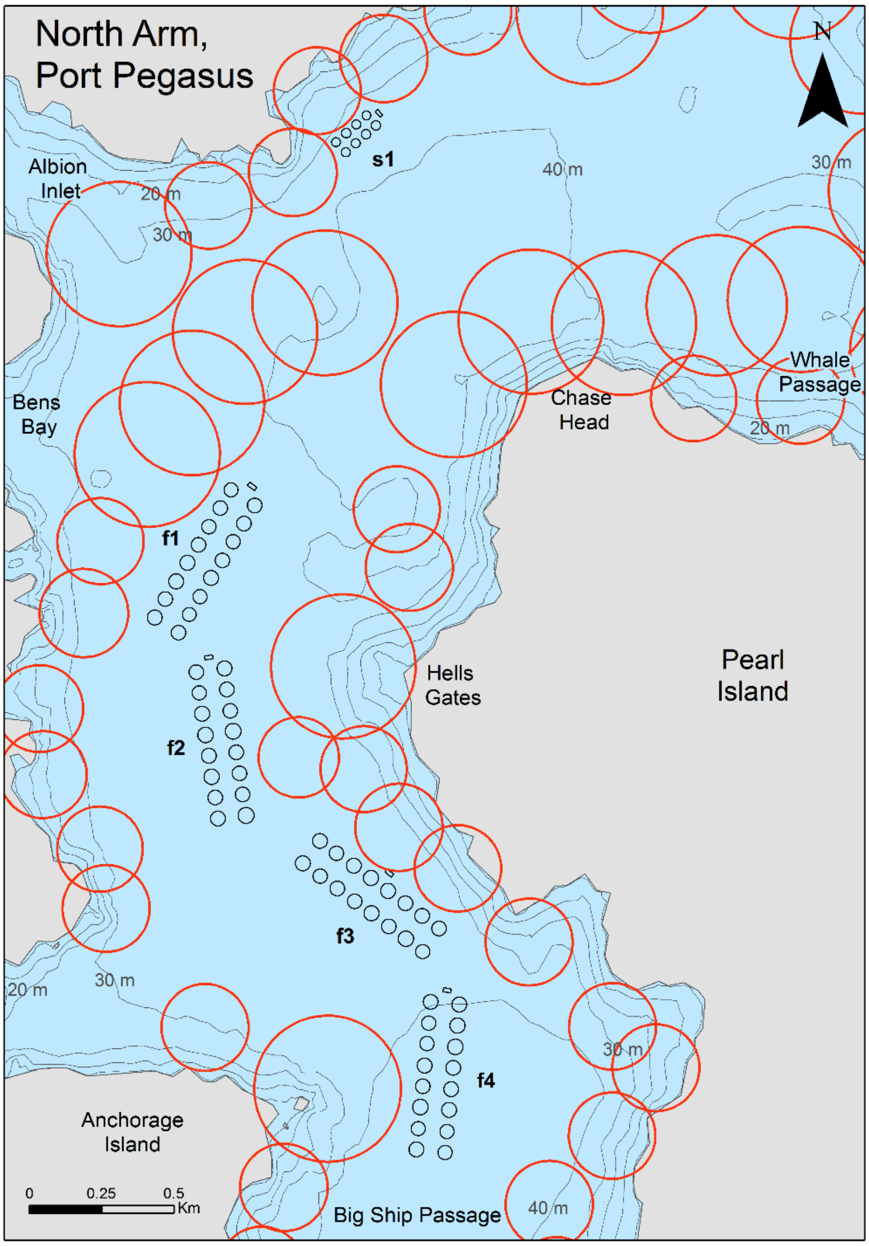

Figure 30. Potential finfish farming locations within North Arm, Port Pegasus/Pikihatiti. The locations of four areas for the grow-out of salmon (f1-f4) and an area for smolt production (s1) are indicated. Red circles indicate exclusion buffers around areas of hard substrate and known black coral locations.

5.3.2. Depositional modelling for farm scenarios

As an indicator of likely production capacity within the North Arm area, varying feed input and cage configuration scenarios were modelled across the farming areas using DEPOMOD v 2.2 (refer to Appendix 10 for DEPOMOD input parameters). Two sets of scenarios were modelled, based on the farming areas operating in a similar way to either low-flow or high-flow sites within the Marlborough Sounds (see Section 5.3).

This does not imply that the sites in Big Ship passage are high-flow sites, rather that some of the sites (particularly the two sites closest to the entrance to Big Ship Passage), may be 'low-flow sites with episodic wave action', which may have a mitigating effect on benthic enrichment. The magnitude of that potential beneficial effect is currently unknown. The use of the high-flow assumption is for comparison purposes only, and does not suggest that the potential effect from waves would be of similar magnitude as high-flow tidal currents in the Marlborough Sounds. The 'high-flow'-based scenarios and their associated potential production figures should therefore be interpreted with caution. It is also important to note that these scenarios were designed to provide indicative potential feed inputs only. Initial and maximum feed levels for each farm site, would be recommended during Stage 3 site-specific assessments (see Section 6).

Maximum feed inputs per pen for each farm area were based on preliminary DEPOMOD assessments for a range of feed inputs for a single pen at each farm area (131–400 t). Feed inputs that resulted in maximum depositional rates of ~6 kg m^{-2} yr^{-1} at the net pen edge were used for DEPOMOD assessments for the low-flow farm scenarios (Scenario 1a–4a; see Table 3). Feed inputs that resulted in maximum depositional rates of ~13 kg m^{-2} yr^{-1} at the net pen edge were used for DEPOMOD assessments for the high-flow farm scenarios (Scenario 1b–4b; see Table 3). These levels of deposition are predicted to result in c. ES 5 conditions if the farm areas operate in a similar way to low-flow or high-flow farm sites in the Marlborough Sounds region, respectively (see Section 5.3).

A maximum of 64 grow-out pens (16 pens per area) across the four farm areas were assessed in the modelling, so maximum production was associated with all pens operating at all farms. Scenarios with lower levels of production were achieved by reducing the number of pens at each of the farm areas. Across the two sets of scenarios, feed input per pen over a 1-year period varied depending on whether the farms were modelled as operating like low-flow or high-flow sites (see Table 3). As the total number of pens varied across scenarios, the total feed input at each farm area also varied. The feed inputs resulted in scenarios with a range of production levels across the site (~2,800–8,000 t production, per annum; see Table 3). The likely production from each scenario was estimated using a feed conversion efficiency (FCE) ratio of 1.7:1.

For the smolt farm, a feed level of 5% of the total feed input across the four grow-out farms was used across the two sets of scenarios (238–680 t per annum; Table 3). Smolt feed was spread evenly across 4, 6 or 8 smolt pens in each scenario, which resulted in feed inputs of 60–102 t per pen (per annum).

Table 3. Farm scenarios and parameters, including feed input per pen (tonnes per annum), number of pens (160 m circumference for grow-out and 100 m circumference for smolt), total feed input and estimated production (tonnes per annum) for the four grow-out areas (f1–f4) and the smolt growing area (s1). Scenarios 1a–4a represent feed input levels that result in ES 5 conditions at the pen edge assuming farms operate like low-flow sites. Scenarios 1b–4b represent feed input levels that result in ES 5 conditions at the pen edge assuming farms operate like high-flow sites[10].

Scenario	Input parameters	Farming area				Grow-out totals	Smolt totals
		f1	f2	f3	f4		
1a	Feed per pen (tonne)	**131**	**131**	**150**	**225**		64
	Number pens	16	16	16	16	64	8
	Total feed (tonne)	2,100	2,100	2,400	3,600	10,200	510
	Total production (FCE 1.7)	1,235	1,235	1,412	2,118	6,000	
2a	Feed per pen (tonne)	**131**	**131**	**150**	**225**		63
	Number pens	8	10	14	14	46	6
	Total feed (tonne)	1,050	1,312.5	2,100	3,150	7,613	381
	Total production (FCE 1.7)	618	772	1,235	1,853	4,478	
3a	Feed per pen (tonne)	**131**	**131**	**150**	**225**		79
	Number pens	6	8	12	12	38	4
	Total feed (tonne)	787.5	1,050	1,800	2,700	6,338	317
	Total production (FCE 1.7)	463	618	1,059	1,588	3,728	
4a	Feed per pen (tonne)	**131**	**131**	**150**	**225**		60
	Number pens	4	6	8	10	28	4
	Total feed (tonne)	525	787.5	1,200	2,250	4,763	238
	Total production (FCE 1.7)	309	463	706	1,324	2,801	
1b	Feed per pen (tonne)	**175**	**175**	**200**	**300**		85
	Number pens	16	16	16	16	64	8
	Total feed (tonne)	2,800	2,800	3,200	4,800	13,600	680
	Total production (FCE 1.7)	1,647	1,647	1,882	2,824	8,000	
2b	Feed per pen (tonne)	**175**	**175**	**200**	**300**		85
	Number pens	8	10	14	14	46	6
	Total feed (tonne)	1,400	1,750	2,800	4,200	10,150	508
	Total production (FCE 1.7)	824	1,029	1,647	2,471	5,971	
3b	Feed per pen (tonne)	**175**	**175**	**200**	**300**		102
	Number pens	6	8	12	12	38	4
	Total feed (tonne)	1,050	1,400	2,400	3,600	8,450	407
	Total production (FCE 1.7)	618	824	1,412	2,118	4,971	
4b	Feed per pen (tonne)	**175**	**175**	**200**	**300**		79
	Number pens	4	6	8	10	28	4
	Total feed (tonne)	700	1,050	1,600	3,000	6,350	317
	Total production (FCE 1.7)	412	618	941	1,765	3,735	

[10] This does not suggest that farm sites are 'high-flow', rather that some of the sites may be 'low-flow sites with episodic wave action', which may have a mitigating effect on benthic enrichment. The magnitude of that potential beneficial effect is currently unknown. If this does not occur regularly, benthic management tools may be required, but these have environmental consequences that require consideration, and some are unproven at a commercial scale in New Zealand (see Section 6.3)

5.3.3. Results of depositional modelling for farm scenarios

Depositional modelling for farms operating similar to low-flow sites (Scenarios 1a–4a; Table 3) resulted in predicted maximum deposition rates of 6.1–8 kg m^{-2} yr^{-1} beyond the net pens at all farm areas (Figures 31 to 34)[11]. The intensity of depositional effects remained similar despite a reduction in the number of pens used, as the amount of feed per pen was constant in each scenario. In all four scenarios, very small patches of 8.1–10 kg m^{-2} yr^{-1} were predicted beneath the pens at f4 (farming area closest to the entrance to Big Ship Passage), which would likely result in enrichment that would exceed EQS. However, over the majority of the area deposition rates were at levels that are likely to be assimilated by benthic communities (i.e. ≤ 6.1–8 kg m^{-2} yr^{-1}, c. ES 5). Under low-flow scenarios, modelled production levels across the whole area ranged from 2,800 to 6,000 t per annum.

Depositional modelling of farm wastes for farms operating in a similar way to high-flow sites (scenarios 1b-4b; Table 3) predicted higher maximum deposition rates (8.1-13 kg m^{-2} yr^{-1}). Deposition was concentrated in small patches beside the net pens at all four farm areas in the main direction of flow (Figure 35 to 38). The higher rates predicted were due to the slight overlap in depositional footprints from each pen and the increased feed input per pen. Seabed enrichment within these small patches is predicted to reach very high levels (c. ES 5) and would be at the upper limit of enrichment effect allowed under the BMP guidelines (MPI 2015). If finfish farming in these areas was to occur at these feed input levels, the use of benthic management options such as fallowing, increased pen spacing, seabed remediation or waste capture to reduce benthic effects may be required at some farm areas (see Section 6.3).

The number of pens and feed inputs modelled at the smolt farm differed between scenarios depending on associated production levels (4 to 8 pens; see Table 3). Associated deposition rates were therefore predicted to change. The low-flow nature of the smolt site resulted in high levels of deposition (> 13 kg m^{-2} yr^{-1}), largely centred directly beneath the pens. At this upper level of deposition, excessive enrichment (c. ES 6) was predicted beneath the pens. However, at the pen edge the maximum deposition was predicted to be 6.1–8 kg m^{-2} yr^{-1} and thus would be more likely to be assimilated by benthic communities. Enrichment effects for this site would likely exceed the upper limit of enrichment effects allowed at the feed levels modelled (c. ES 6), and would likely require management options such as fallowing, waste capture, or seabed remediation to maintain a healthy seabed over successive years (see Section 6.3).

[11] This range encompasses the approximate amount of deposition at which ES 5 effects are expected (i.e. approximately 6 kg m^{-2} yr^{-1}). Stage 3 site-specific assessments will be required to determine initial and predicted sustainable feed levels once actual farm sites and scenarios are decided. These assessments will include finer-scale deposition estimates.

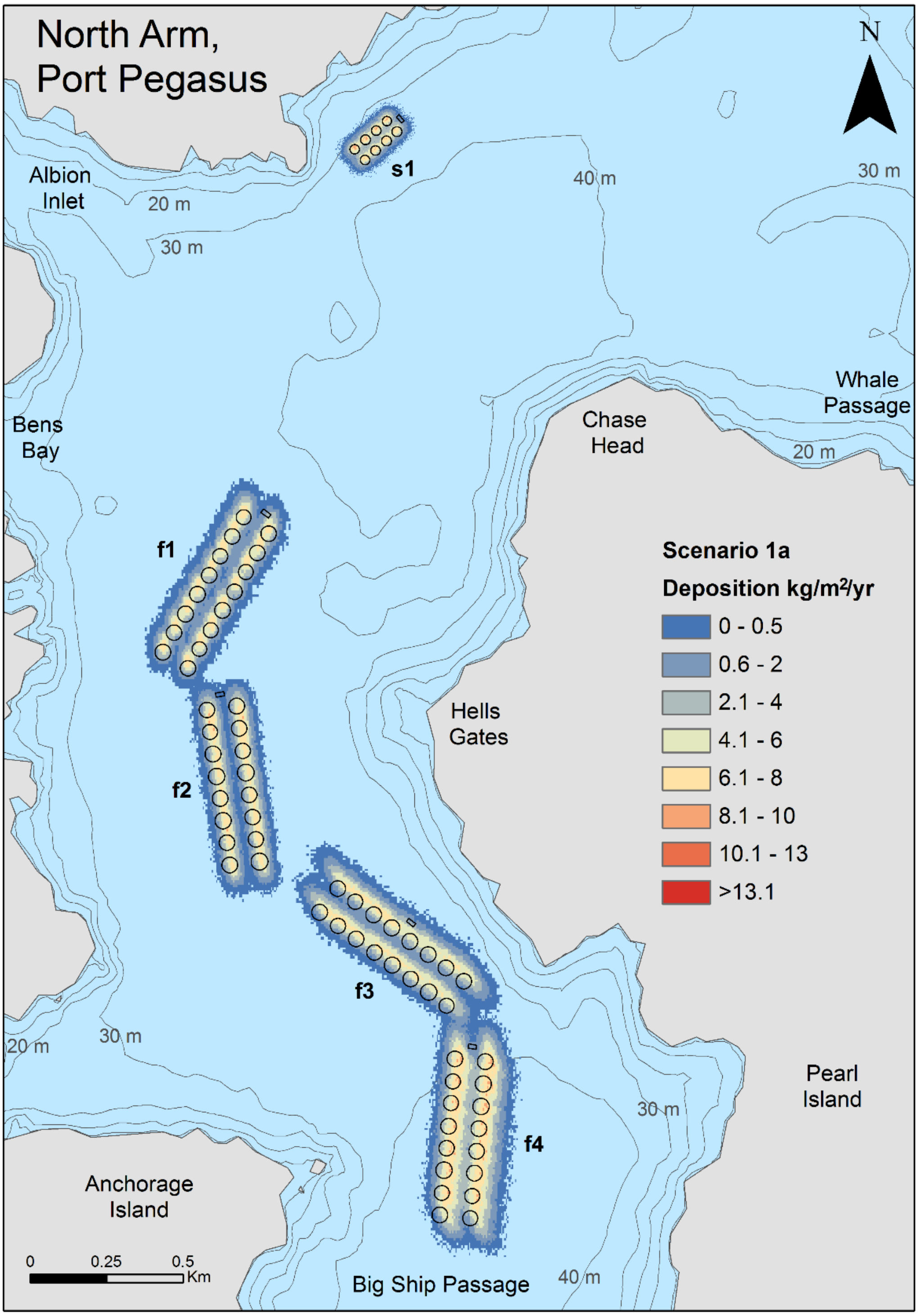

Figure 31. Depositional rates for Scenario 1a at four grow-out farm areas (f1–f4) and a smolt farm area (s1) within North Arm, Port Pegasus/Pikihatiti. Total feed input across the farm areas was 10,200 tonne per annum (f1: 2,100 tonne; f2: 2,100 tonne; f3: 2,400 tonne; and f4: 3,600 tonne), spread evenly across 16 x 160 m circumference pens within each area. Total feed input at the smolt area was 510 tonne per annum, spread evenly across 8 x 100 m circumference pens.

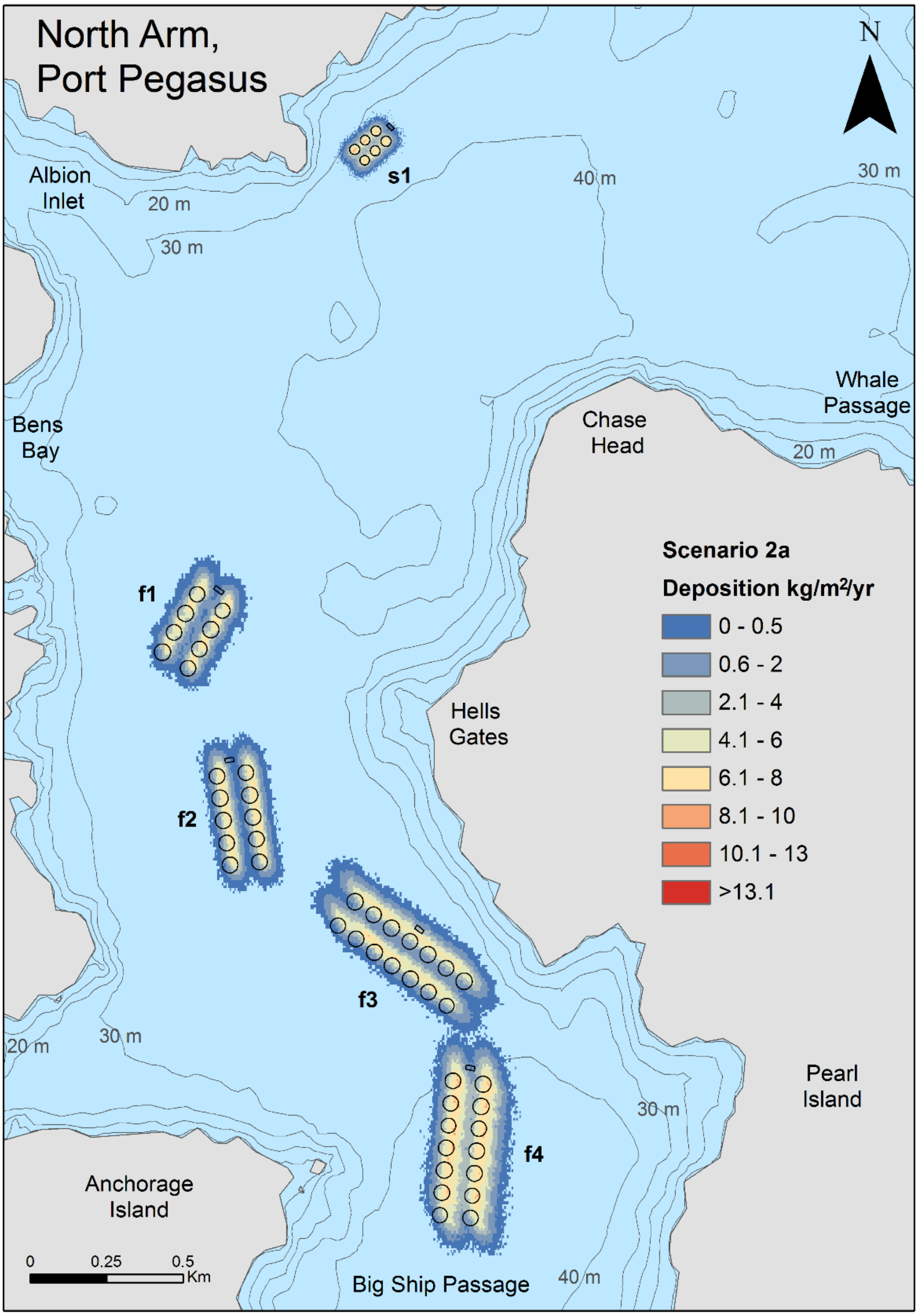

Figure 32. Depositional rates for Scenario 2a at four grow-out farm areas (f1–f4) and a smolt farm area (s1) within North Arm, Port Pegasus/Pikihatiti. Total feed input across the farm areas was 7,613 tonne per annum (f1: 1,050 tonne; f2: 1,313 tonne; f3: 2,100 tonne; and f4: 3,150 tonne), spread evenly across 8 pens at f1, 10 pens at f2, 14 pens at f3 and 14 pens at f4. All grow-out pens are 160 m circumference. Total feed input at the smolt area was 318 tonne per annum, spread evenly across 6 x 100 m circumference pens.

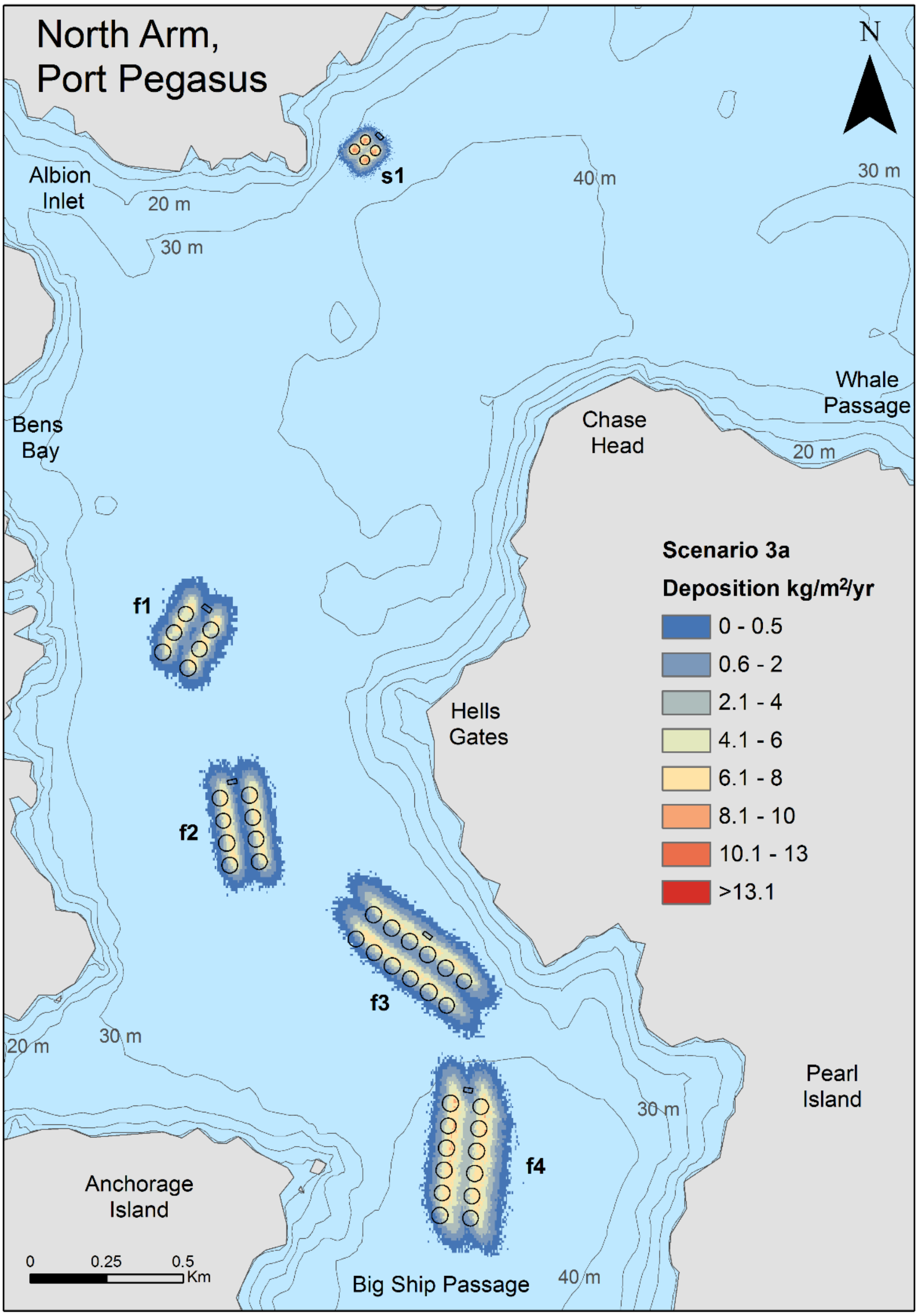

Figure 33. Depositional rates for Scenario 3a at four grow-out farm areas (f1–f4) and a smolt farm area (s1) within North Arm, Port Pegasus/Pikihatiti. Total feed input across the farm areas was 6,338 tonne per annum (f1: 788 tonne; f2: 1,050 tonne; f3: 1,800 tonne; and f4: 2,700 tonne), spread evenly across 6 pens at f1, 8 pens at f2, 12 pens at f3 and 12 pens at f4. All grow-out pens are 160 m circumference. Total feed input at the smolt area was 317 tonne per annum, spread evenly across 4 x 100 m circumference pens.

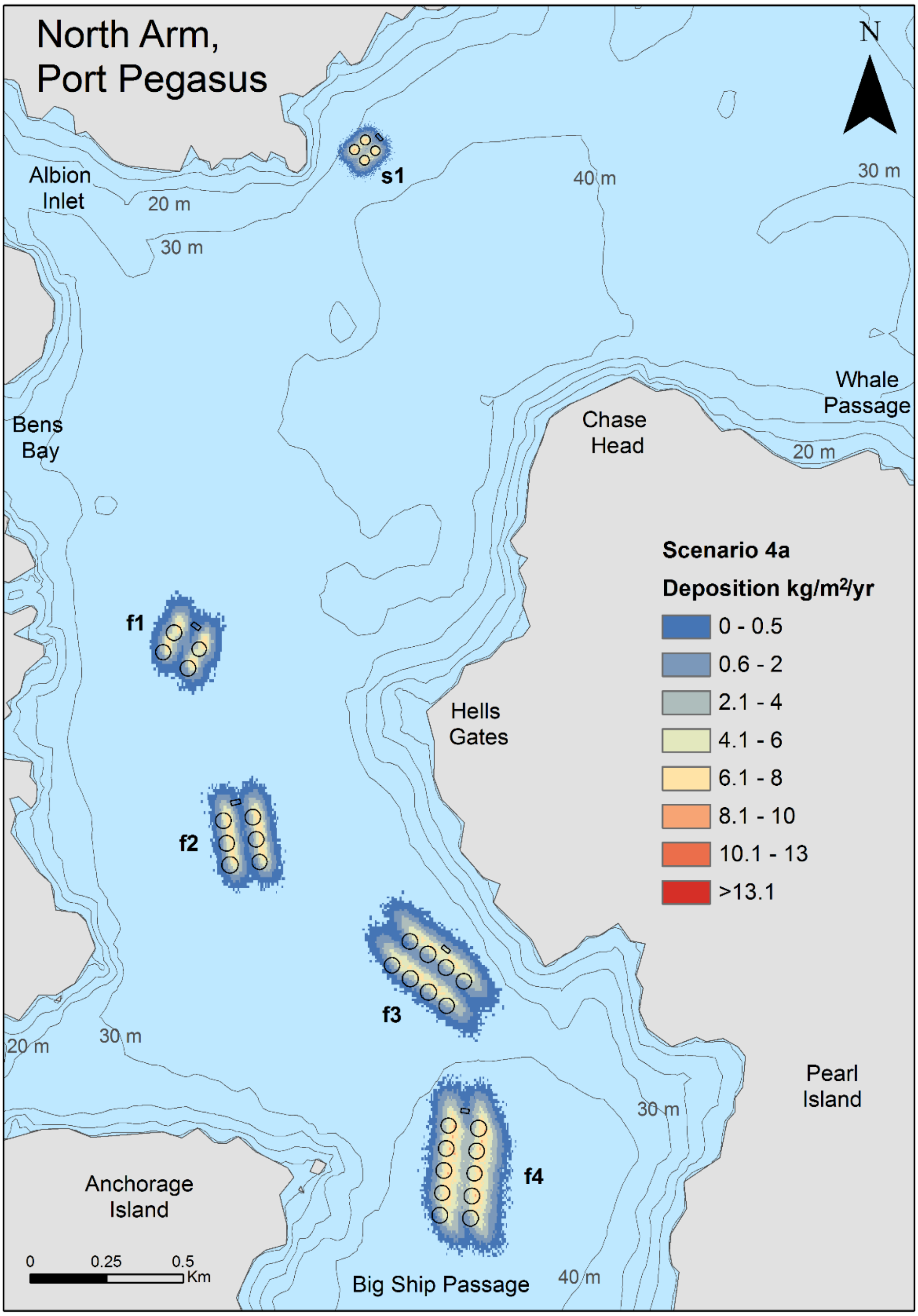

Figure 34. Depositional rates for Scenario 4a at four grow-out farm areas (f1–f4) and a smolt farm area (s1) within North Arm, Port Pegasus/Pikihatiti. Total feed input across the farm areas was 4,763 tonne per annum (f1: 525 tonne; f2: 788 tonne; f3: 1,200 tonne; and f4: 2,250 tonne), spread evenly across 4 pens at f1, 6 pens at f2, 8 pens at f3 and 10 pens at f4. All grow-out pens are 160 m circumference. Total feed input at the smolt area was 238 tonne per annum, spread evenly across 4 x 100 m circumference pens.

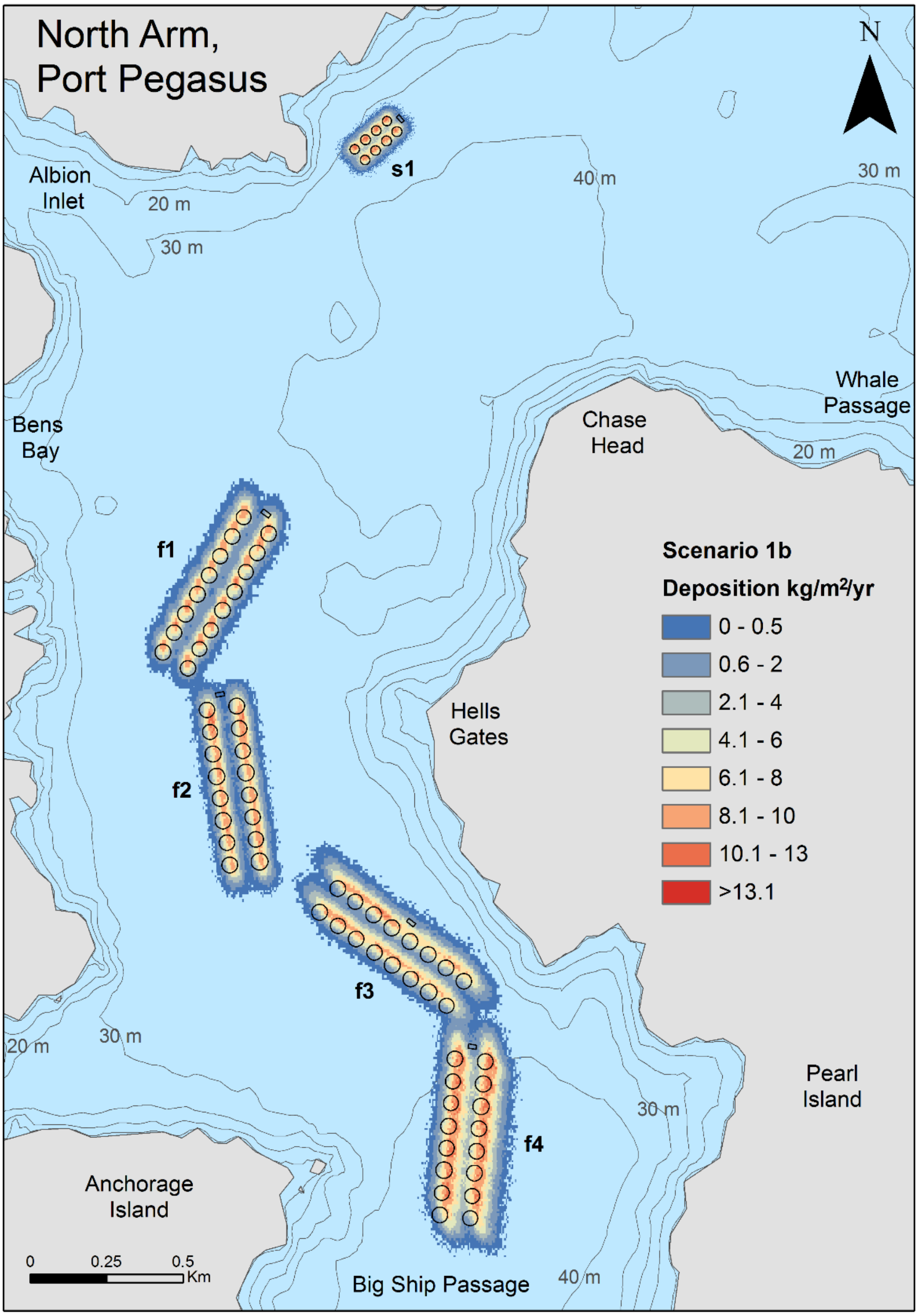

Figure 35. Depositional rates for Scenario 1b at four grow-out farm areas (f1–f4) and a smolt farm area (s1) within North Arm, Port Pegasus/Pikihatiti. Total feed input across the farm areas was 13,600 tonne per annum (f1: 2,800 tonne; f2: 2,800 tonne; f3: 3,200 tonne; and f4: 4,800 tonne), spread evenly across 16 x 160 m circumference pens within each area. Total feed input at the smolt area was 680 tonne per annum, spread evenly across 8 x 100 m circumference pens.

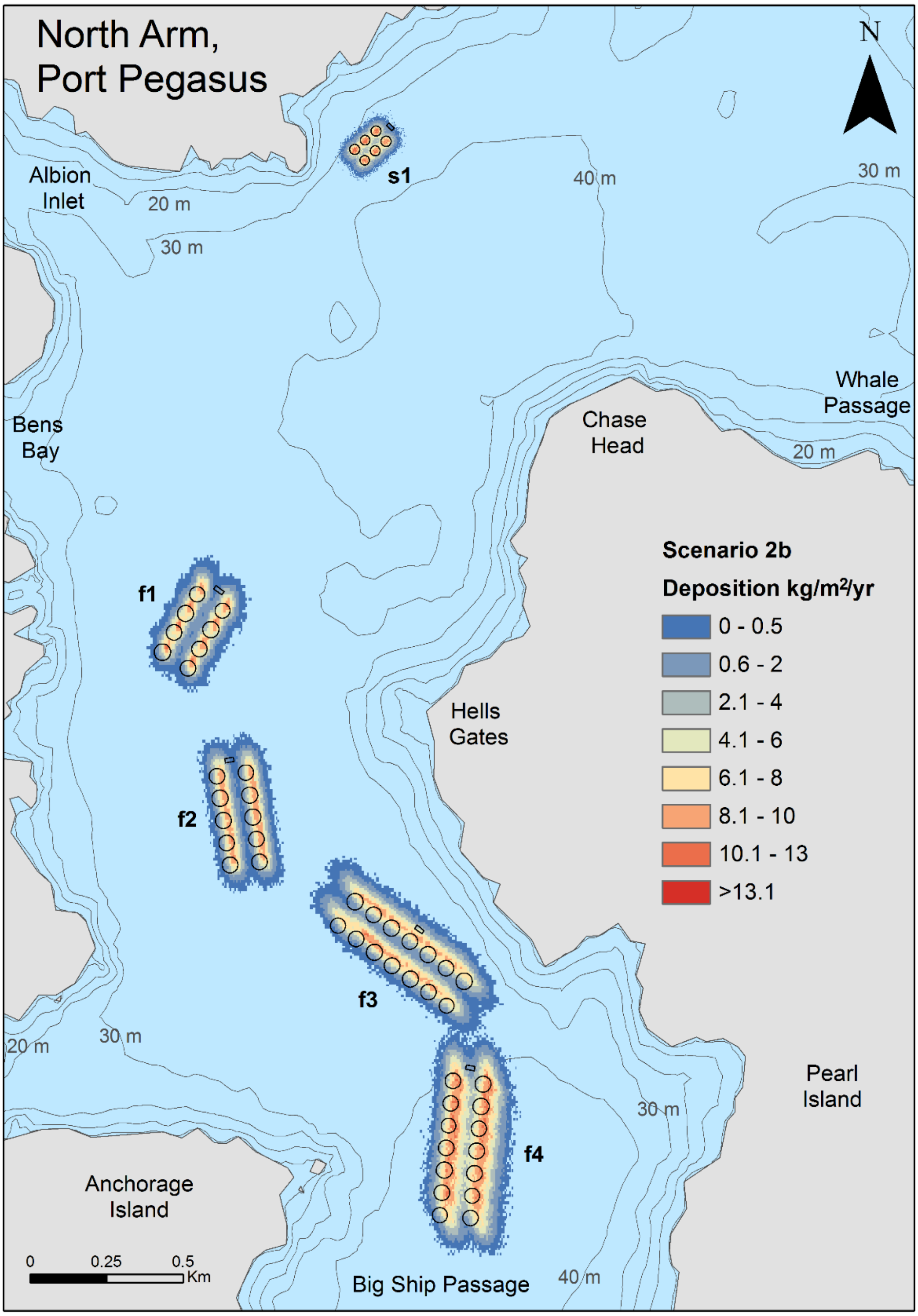

Figure 36. Depositional rates for Scenario 2b at four grow-out farm areas (f1–f4) and a smolt farm area (s1) within North Arm, Port Pegasus/Pikihatiti. Total feed input across the farm areas was 10,150 tonne per annum (f1: 1,400 tonne; f2: 1,750 tonne; f3: 2,800 tonne; and f4: 4,200 tonne), spread evenly across 8 pens at f1, 10 pens at f2, 14 pens at f3 and 14 pens at f4. All grow-out pens are 160 m circumference. Total feed input at the smolt area was 508 tonne per annum, spread evenly across 6 x 100 m circumference pens.

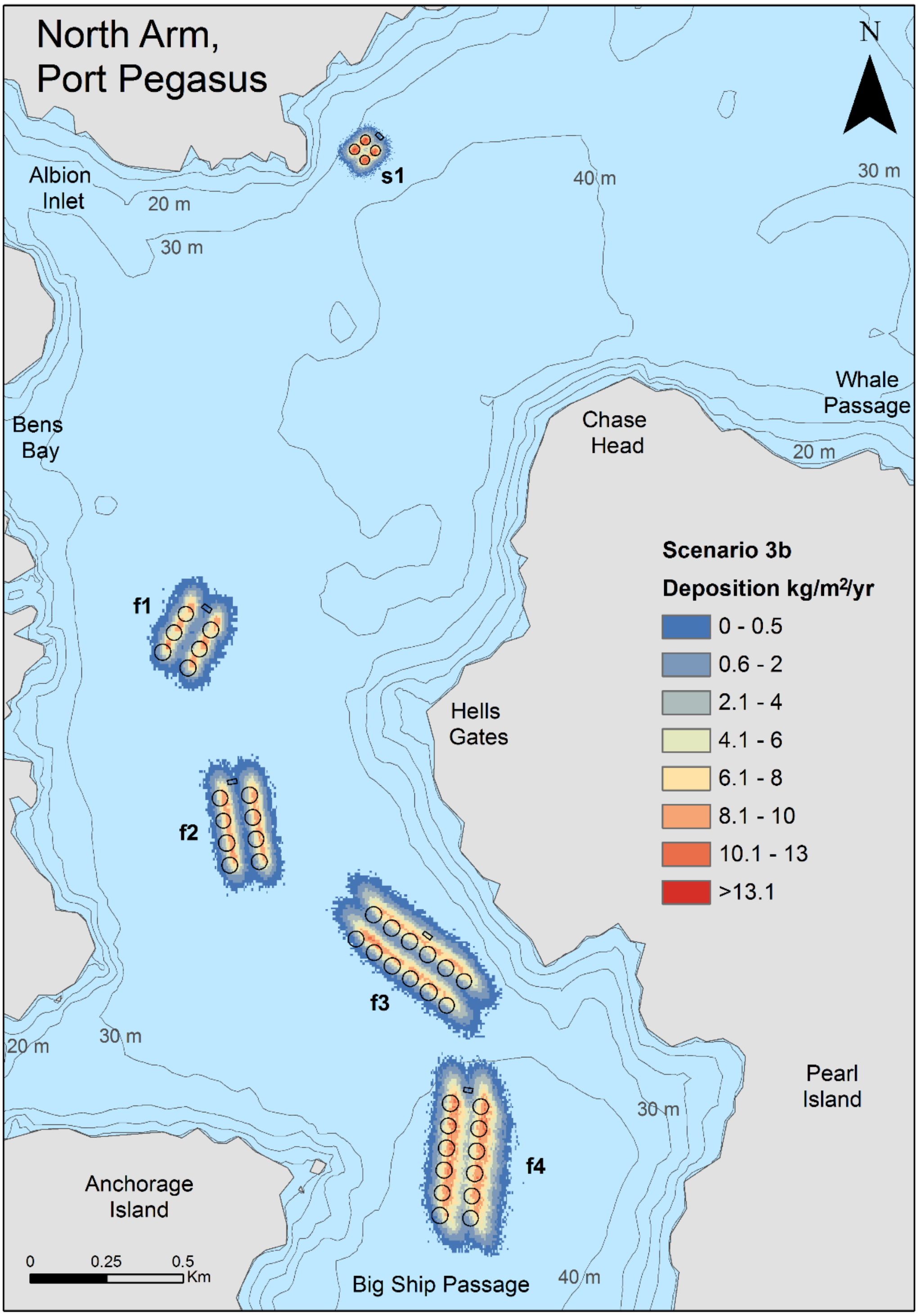

Figure 37. Depositional rates for Scenario 3b at four grow-out farm areas (f1–f4) and a smolt farm area (s1) within North Arm, Port Pegasus/Pikihatiti. Total feed input across the farm areas was 8,450 tonne per annum (f1: 1,050 tonne; f2: 1,400 tonne; f3: 2,400 tonne; and f4: 3,600 tonne), spread evenly across 6 pens at f1, 8 pens at f2, 12 pens at f3 and 12 pens at f4. All grow-out pens are 160 m circumference. Total feed input at the smolt area was 407 tonne per annum, spread evenly across 4 x 100 m circumference pens.

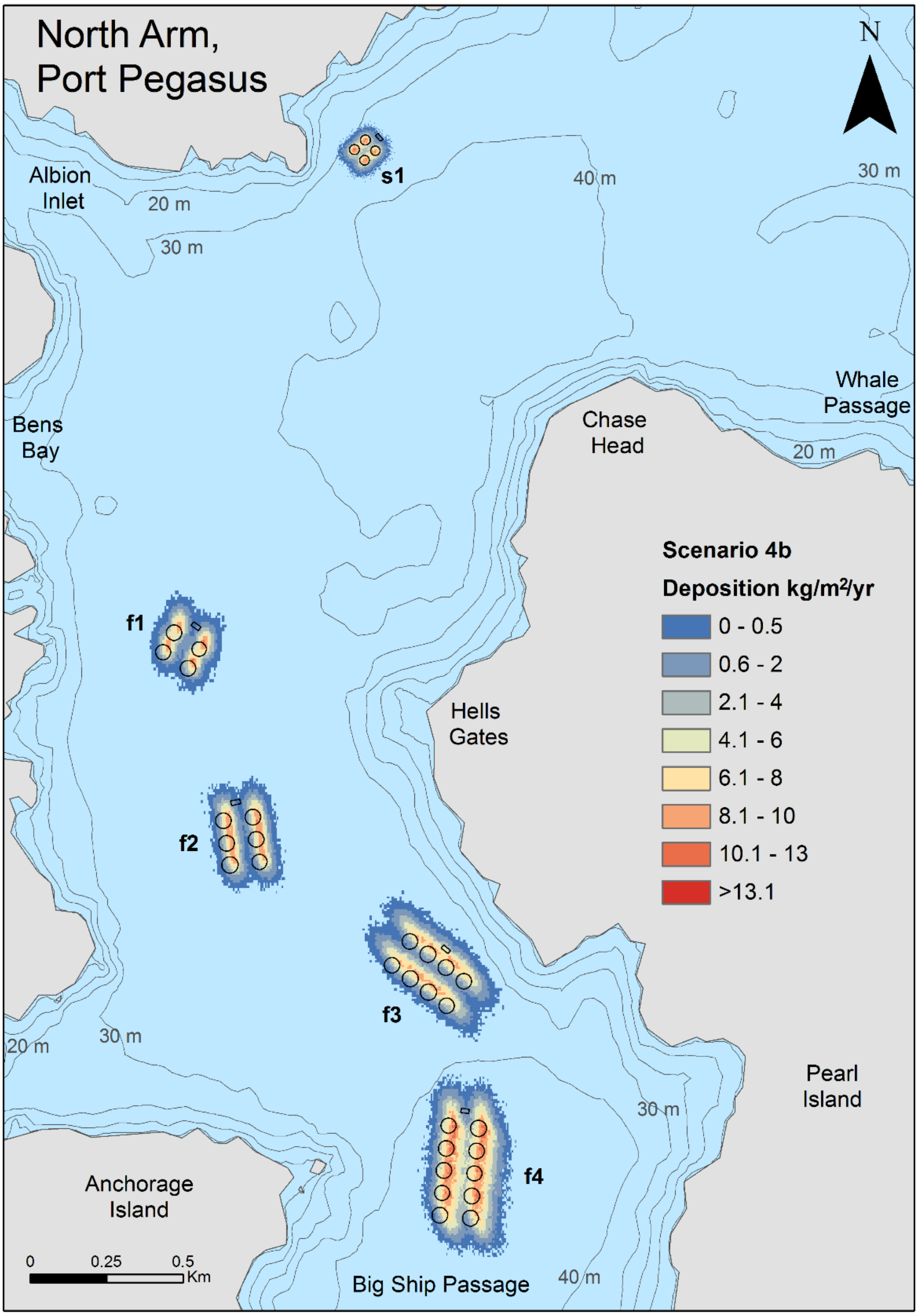

Figure 38. Depositional rates for Scenario 4b at four grow-out farm areas (f1–f4) and a smolt farm area (s1) within North Arm, Port Pegasus/Pikihatiti. Total feed input across the farm areas was 6,350 tonne per annum (f1: 700 tonne; f2: 1,050 tonne; f3: 1,600 tonne; and f4: 3,000 tonne), spread evenly across 4 pens at f1, 6 pens at f2, 8 pens at f3 and 10 pens at f4. All grow-out pens are 160 m circumference. Total feed input at the smolt area was 317 tonne per annum, spread evenly across 4 x 100 m circumference pens.

5.4. Predicted benthic effects from farm scenarios

The effects of finfish farm-related biodeposits and associated enrichment on the seabed environment have been well documented, including a review specific to aquaculture in New Zealand (MPI 2013). By placing farms over predominantly sand and mud habitats, with generally sparse epibiota, effects on the seabed and associated fauna are likely to closely follow those of other finfish farms in low-flow environments. Epifauna are likely to be displaced directly beneath net pens; however, some species (in particular brittle stars, *Ophiopsammus maculata*) may proliferate at the pen edge and surrounding areas due to the increased abundance of biofouling drop-off from the net pens and associated structures. Up to a point (c. ES 5), the total abundance of infaunal taxa (i.e. animals living within the sediment) is likely to increase, after which taxa richness will decrease as farm-related benthic deposits and enrichment levels increase (MPI 2015). If deposition and enrichment go beyond the point where it can be assimilated by the benthic communities, the seabed will tend towards anoxic and azoic conditions.

The magnitude of depositional effects on the seabed within the North Arm area will largely be dependent on the amount of feed input and the total area of the net pens. Uncertainty around whether the farm areas will operate in a manner similar to low- or high-flow sites within the Marlborough Sounds region makes predictions of benthic effects challenging. There is the potential for episodic wave events to resuspend and disperse farm deposits at farm sites closer to the entrance to Big Ship Passage (see the associated pelagic biophysical report; Knight et al. 2017). A summary of predicted benthic effects is provided:

- DEPOMOD outputs suggest that detectable farm-related effects will remain within c.150 m of net pens, due to the low-flow nature of the sites.
- Depending on the location within Big Ship Passage, depositional modelling results suggest that feed inputs of c. 131–225 t per 160 m circumference pen (per annum) would result in levels of biodeposition approaching sustainable levels (i.e. c. ES 5). In some scenarios the predicted deposition was at the upper limit or exceeded sustainable levels. Further depositional modelling during Stage 3 site-specific assessments is recommended to set initial and likely sustainable feed inputs.
- Adverse effects on habitats and taxa of ecological significance are considered unlikely, due to the combination of buffer exclusion zones surrounding these features and the relatively low-flow nature of the area.
- Management options such as fallowing, increased pen spacing, seabed remediation or waste capture[12] may be required in some cases to maintain a healthy seabed over successive years if feed input per pen approached, or exceeded, the upper limits of the amounts modelled here (see Section 6.3).

[12] Seabed remediation and waste capture are in the early stages of commercial development and application overseas and in New Zealand. Fallowing has been tested in the Marlborough region but requires additional farm area. For further discussion on potential benthic management options see Section 6.3.

6. MANAGING BENTHIC EFFECTS

Best Management Practice (BMP) guidelines for salmon farms in the Marlborough Sounds region have been developed by a benthic standards working group (MPI 2015). The BMP guidelines outline Environmental Quality Standards (EQS), contain the most up-to-date monitoring protocols, and discuss potential management responses relating to benthic effects from salmon farming in New Zealand. We recommend that the BMP guidelines are adopted as a framework to manage benthic effects relating to any salmon farm development in Port Pegasus/Pikihatiti.

6.1. Adapting the BMP guidelines to Port Pegasus/Pikihatiti

The BMP document was intended to be used as a guide for developing benthic monitoring programs for salmon farms in the Marlborough Sounds (MPI 2015). It was intended to be a working document that would be reviewed and updated as knowledge and methodologies evolve. While the methods described in the BMP guidelines are proving to be applicable for other areas, some adjustment may be required for site-specific conditions. For example, the presence of sand waves in parts of Big Ship Passage suggest that the benthic environment will be more prone to disturbance from weather events (i.e. long-period swell and wind-driven currents) than low-flow sites in the Marlborough Sounds region. Consequently, resuspension and redistribution of farm wastes may cause the farm areas to alternate from low-flow depositional sites (i.e. during calm weather conditions), to more dispersive sites during large wave events (see sections 3.2.5 and 6 in Knight et al. 2017). These events may periodically increase near-bottom current speeds and induce resuspension of sediments at the seabed. This has the potential to dilute and disperse waste particles, resulting in a wider, more diffuse depositional footprint, relative to the more conventional low-flow farms. Significant resuspension events can also interrupt the development of opportunistic species; as such, a stage of 'peak abundance', which aids in assessing enrichment level, may not be as apparent as in usual low-flow conditions.

6.2. Applying a staged approach to development

While modelling is a useful tool for predicting environmental effects and gauging site-specific feed capacities, it is a theoretical-based predictive tool and the results should be applied in a conservative manner. A recommended conservative approach to finfish farm developments involves starting at relatively low production levels, staging the development while monitoring for effects, and making future expansions conditional upon acceptable environmental outcomes.

If more detailed studies of the benthic and water column environments (i.e. Stage 3 site-specific assessments) show that the North Arm area is suitable for finfish farming, we would recommend a staged approach to development. Critical aspects of a staged-development approach include: (i) the sizes and frequencies of incremental increases in feed input and associated production; and (ii) the environmental monitoring criteria that determine the effects of subsequent increases. The latter is largely covered by the BMP guidelines and it is recommended that if finfish aquaculture proceeds, this document is used as an initial monitoring and management framework for benthic effects. An example of how a staged-development approach might be applied to the North Arm region (adapted from Keeley and Taylor 2011) has been provided in Box 1 below:

Box 1: Example of a staged approach to aquaculture development in North Arm

It is recommended that feed input increases be implemented with a few large increments rather than many small ones, such that the effects of each step are apparent and fully realised before progressing to the next stage. In determining the frequency or period between increments, the main points to consider are: (i) how long it might take to reach the upper limit of the existing feed capacity; (ii) how long it takes for the full effects to be expressed in the environment; and (iii) how long it takes to demonstrate that the effects have stabilised. We recommend a minimum of three years between increases in feed input and that the following be demonstrated prior to this occurring:

- the site has been operating at or near the maximum specified annual feed capacity for that period (i.e. within ±15% of an initial maximum feed level),
- seabed effects appear to have stabilised (i.e. the results of at least the last two years environmental monitoring surveys are comparable), and
- the site has remained compliant with the environmental quality standards outlined in the BMP guidelines (MPI 2015).

As part of a Stage 3 assessment, recommended initial feed levels (RIFL) and predicted sustainable field levels (PSFL) should be estimated for each of the proposed farming areas. The PSFL will represent a best estimate (based on modelling and experience) of the amount of feed the area can assimilate without seabed effects becoming unacceptable (ES > 5, according to BMP guidelines; MPI 2015). The RIFL will be c. 75% of PSFL and will provide a conservative estimate of an appropriate initial feed input level from which any step-wise increases, at set maximum tonnages and frequencies, may occur (dependent upon the results of annual environmental monitoring surveys).

6.3. Potential management options for seabed effects

There are several potential options for managing benthic effects beneath salmon farms; only some have been tested in New Zealand and others are in various stages of development. Benthic management tools have the potential to reduce the intensity of enrichment effects on the seabed; however, each tool generally has an associated environmental cost. Management options for seabed effects include:

- limiting the total amount of feed input per pen
- increasing the spacing between pens
- farming a single year-class and fallowing for 2–3 months
- moving to adjacent fallowing sites
- capturing faeces and feed before it reaches the seabed
- seabed remediation (e.g. by occasional vacuum dredging).

Limiting feed inputs to each pen has the environmental cost of requiring a much larger number, and therefore area, of net pens to produce a set amount of fish. This will have the environmental consequence of affecting and enriching a larger area of seabed, albeit at a lower intensity. Increasing pen spacing, while decreasing any overlap of depositional footprints, will also require a larger area of seabed to be affected by farm-related enrichment in order to achieve the same production.

Single year-class farming is used in Norway, whereby fish are able to be farmed on a site for 22 out of every 24 months. This requires sites to be fallowed for 2 months, after which time the feed input would be slowly increased as smolt are re-introduced to the site and on-grown. This method of reducing benthic effects would also require a larger number of farms, with an increased area of seabed affected to produce a set tonnage of fish.

Fallowing of farm areas is also an option for management of benthic effects. Farms would be moved to an adjacent area after a set period of time (e.g. every 24 months) (Figure 39). This would enable the seabed beneath a farmed area to recover to some degree, before farming at this site is reinstated. Again, this option would have the environmental cost of affecting a larger area of seabed with farm-related deposits, in order to achieve the same production, but to a lower intensity than if farms were to remain in one location.

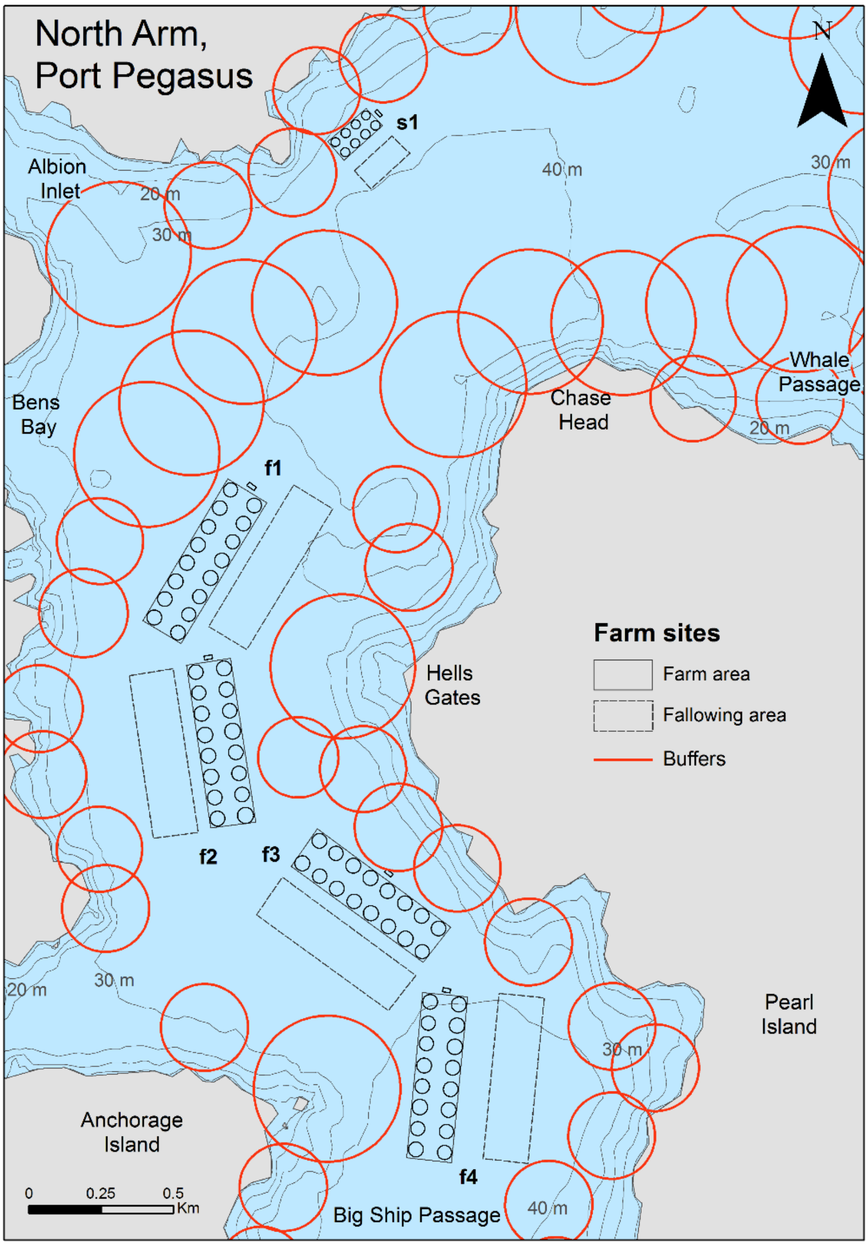

Figure 39. Grow-out farm areas (f1–f4) and a smolt farm area (s1) within North Arm, Port Pegasus/Pikihatiti, with potential adjacent fallowing areas indicated (dashed rectangles).

Methods for capturing faeces and uneaten feed before they reach the seabed are in the early stages of research and commercial development in Australasia. The concept involves collection of faeces and uneaten feed in a large funnel that is suspended beneath the farm, which is then pumped to holding bags on a barge. A related concept is seabed remediation in which farm-related biodeposits are removed from the seabed surface, allowing for more rapid recovery after fallowing. Seabed remediation has been successfully trialled at an experimental scale in the Marlborough Sounds region. A semi-commercial scale research study of seabed remediation in Marlborough is planned in the coming months. At a commercial scale a small vacuum dredge head would be used to remove the top 5–10 cm of organic matter from the seabed, which would be pumped to holding bags on a barge for later disposal. Both methods are unlikely to collect or remove all farm-related wastes; however, if a significant proportion of farm-related biodeposits could be removed there would likely be considerable benefits to the benthic environment beneath farms as well as decreased fallowing time required for benthic recovery. Disposal of collected waste will require de-watering and desalinating, and possibly dilution to reduce high levels of zinc (from feed), before it can be used on land. If disposal was to be at sea, there would be an associated environmental cost with spreading farm waste over a much larger area, albeit at a much lower intensity.

None of the above methods are likely to constitute a ‘silver bullet’ for managing farm deposition effects. Instead, the greatest benefits to the seabed environment are likely to arise from a combination of management methods, which may enable more sustainable production in areas that would not currently meet benthic guidelines.

7. CONCLUSIONS

The seabed in North Arm can be broadly separated into two areas: an area to the north of Pearl Island, comprising soft-sediment habitats with higher proportions of mud particles and with mud-tolerant infaunal communities; and an area to west of Pearl Island, comprising soft-sediment habitats with higher proportions of sand particles and with infaunal communities tolerant of a more mobile substratum. The separation of sediment types based on visual habitat assessments (i.e. drop-camera and video sled footage) was supported by grain-size and macrofaunal assemblage analysis from 45 sediment samples from across the region. Several areas of rocky reef habitat were also identified, the most significant extending into the mid-channel area from Bens Bay. These areas supported a diverse range of invertebrate and fish species.

In general, soft-sediment habitats within North Arm supported relatively sparse epifaunal assemblages when compared to similar semi-sheltered inshore environments around Stewart Island/Rakiura. Isolated areas of high epifaunal diversity were noted, in particular associated with the coarse sand/cobble habitat identified near to the entrance to Whale Passage. Several taxa of ecological significance were identified within the surveyed area, including brachiopods, black coral, sea pens, tube-dwelling anemones and several large bivalve taxa. In general, these taxa were sparsely distributed (< 1 per 10 m^2), and largely centred across areas of mud substrates to the north and northwest of Pearl Island. However, patches of increased abundance were found closer to patch reefs and within cobble habitats near to the entrance of Whale Passage.

Macrofaunal communities present within North Arm are broadly representative of similar unimpacted environments. In general, total abundance of infaunal taxa was higher in northern sites, particularly within muddier sites towards the middle of the bay. Species richness (number of different taxa) was more consistent across the North Arm region. An exception was the site closest to the entrance to Whale Passage, which had species richness almost double that of the majority of other samples. Enrichment Stage (ES) scores were generally low across the North Arm region, reflecting natural conditions in the range of low-to-minor enrichment. In general, ES scores were slightly higher in the muddier sediments north of Hells Gates. This increased enrichment will most likely be natural and is possibly due to the close proximity of these sites to riverine inputs, reflecting the higher levels of organic content present within sediments at these sites.

Subsequent depositional modelling of farm wastes from four potential finfish farming areas within Big Ship Passage (identified based on exclusion buffer zones and the Index of Suitable Location assessment) indicated the magnitude of depositional effects on the seabed will largely be dependent on the amount of feed input and the total area of the net pens. Uncertainty around whether the farm areas will operate in a manner similar to low- or high-flow sites within the Marlborough Sounds region makes predictions of associated benthic effects challenging. If the farms were to operate in a manner similar to low-flow sites in the Marlborough Sounds region, production of between 2,800 and 6,000 tonnes per year is predicted, while adhering to BMP guidelines. If some of the farms operate in a similar manner to high-flow sites, due to wave-induced resuspension of deposits (and as such can have higher levels of feed input per pen), seabed enrichment is predicted to reach very high levels within small patches near to the pen edge. Assuming waste dispersal and assimilation similar to 'high-flow' sites, seabed enrichment at the four higher production scenarios modelled (3,700–8,000 tonnes per year) is likely be at the upper limit of effect allowed under the BMP guidelines. Development of initial and predicted sustainable feed levels will be required during Stage 3 site-specific assessments, which would require additional feed input scenarios and deposition modelling.

If finfish farming is deemed appropriate in North Arm, we recommend a staged approach to development. This is due to the low-flow nature of the area and uncertainty around the effects of wave action on the seabed beneath the proposed farms in the Big Ship Passage area. We recommend that the BMP guidelines (MPI 2015) are used as an initial framework for monitoring and managing seabed effects if the proposal to develop finfish aquaculture in the area progresses. Some site-specific adjustments to the BMP may be necessary over time, due to uncertainty around the role that wave action will play in seabed enrichment trajectories. Any site-specific adjustments to the BMP guidelines would need to be guided by several years of seabed monitoring.

If finfish farming were to progress within North Arm, benthic management tools (e.g. fallowing, seabed remediation, waste capture) may be required. While many of these are still in the early stages of development, there are possible environmental benefits from considering their use as they advance to commercial scale application. In most cases, we believe it will require a combination of benthic management methods to achieve long-term environmentally sustainable outcomes. However, if these methods prove successful in reducing effects to the seabed environment, they have potential to enable greater production while meeting benthic best management practice guidelines.

8. ACKNOWLEDGEMENTS

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10. APPENDICES

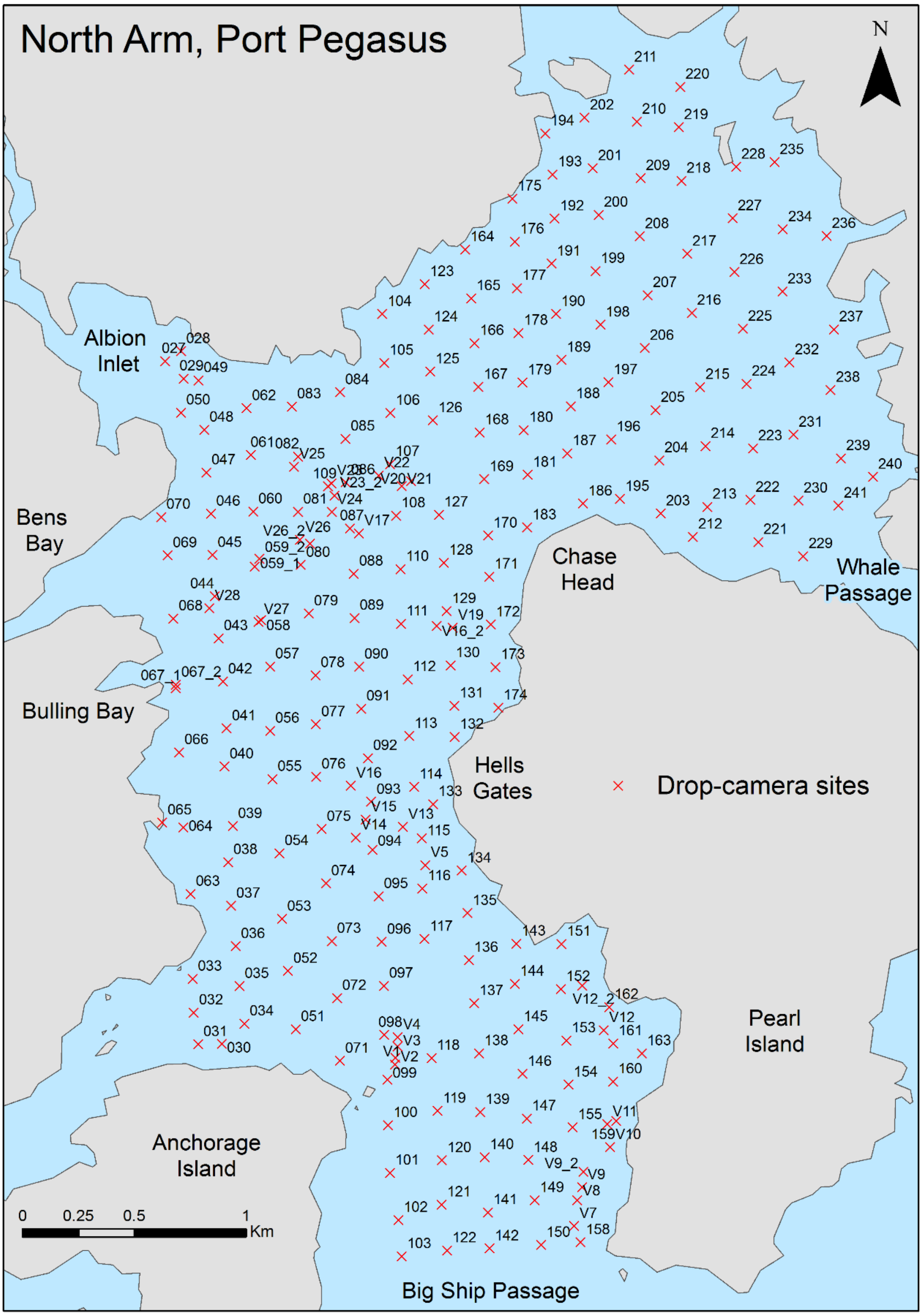
Appendix 1. Laboratory analytical methods for sediment samples processed by Hill Laboratories.

Analyte	Method	Default detection limit
Particle grain-size	Wet sieving using dispersant with gravimetric calculation applied. Seven size classes applied based on the Udden-Wentworth scale: ≥ 2 mm = Gravel ≥ 1 mm - < 2 mm = Very Coarse Sand ≥ 500 µm - < 1 mm = Coarse Sand ≥ 250 µm - < 500 µm = Medium Sand ≥ 125 µm - < 250 µm = Fine Sand ≥ 63 µm - < 125 µm = Very Fine Sand < 63 µm = Mud (Silt & Clay)	0.1 g/100 g dry wt
Organic matter (as ash-free dry weight; AFDW)	Ignition in muffle furnace 550°C, 6hr, gravimetric. APHA 2540 G 22nd ed. 2012.Calculation: 100 - Ash (dry weight).	0.04 g/100 g dry wt

Appendix 2. Definitions of selected biological indicators.

Indicator	Calculation and description	Source
N	Sum (n) Total infauna abundance = number of individuals per 13 cm diameter core	-
S	Count (taxa) Taxa richness = number of taxa per 13 cm diameter core	-
d	(S-1) / log N Margalef's diversity index. Ranges from 0 (very low diversity) to ~12 (very high diversity)	Margalef (1958)
J'	*H'* / log S Pielou's evenness. A measure of equitability, or how evenly the individuals are distributed among the different species. Values can range from 0.00 to 1.00, a high value indicates an even distribution and a low value indicates an uneven distribution or dominance by a few taxa.	Pielou (1966)
H'	$-\sum_i p_i \log(p_i)$ where p is the proportion of the total count arising from the *i*th species Shannon-Weiner diversity index (SWDI). A diversity index that describes, in a single number, the different types and amounts of animals present in a collection. Varies with both the number of species and the relative distribution of individual organisms among the species. The index ranges from 0 for communities containing a single species to high values for communities containing many species with each represented by a small number of individuals.	-
AMBI	= [(0 × %GI + 1.5 × %GII + 3 × %GIII + 4.5 × % GIV + 6 × %GV)]/100 where GI, GII, GIII, GIV and GV are ecological groups (see Section 2.3). Azites Marine Biotic Index: relies on the distribution of individual abundances of soft-bottom communities according to five Ecological Groups (GI-GV). GI being species sensitive to organic pollution and present under unpolluted conditions, whereas, at the other end of the spectrum, GV species are first order opportunists adapted to pronounced unbalanced situations (i.e. *Capitella capitata*). Index values are between 1 (normal) and 6 (extremely disturbed)	Borja et al. (2000)
M-AMBI	Uses AMBI, S and H', combined with factor analysis and discriminant analysis. Multivariate-AMBI. Integrates the AMBI with measures of species richness and SWDI using discriminant analysis (DA) and factorial analysis (FA) techniques. Utilises reference conditions for each parameter (based on 'pristine conditions') that allows the index to be tailored to accommodate environments with different base ecological characteristics. Scores are from 1 (high ecological quality) to 0 (low ecological quality).	Muxika et al. (2007)
BQI	$= (\sum_{i=1}^{n}(\frac{A_i}{totA} \times \text{ES50}_{0.05i})) \times {}^{10}\log(S+1)$ Where ES50 = expected number of species as per Hurlbert (1971) And, $\text{ES50}_{0.05}$ the species tolerance value, given here as the 5^{th} percentile of the ES50 scores for the given taxa as per Rosenberg *et al.* (2004). Benthic quality index: uses species specific tolerance scores ($\text{ES50}_{0.05}$), abundance and diversity factors. Results can range from 0 (being highly impacted) and 20 (reference conditions).	Rosenberg et al. (2004)

Appendix 3. Depth, location and substrate type and texture for drop-camera sites throughout North Arm, Port Pegasus/Pikihatiti. Substrate information for sites without associated video files were estimated and are indicated.



Appendix 3, continued.

SiteID	Depth (m)	Latitude	Longitude	Broad habitat	Substratum texture
27	26.2	-47 10 13.1	167 40 32.0	Mud	Mud with sand
28	22.8	-47 10 11.8	167 40 35.5	Mud	Mud with sand
29	28.2	-47 10 15.8	167 40 35.7	Mud	Mud with sand
30	22.6	-47 11 52.4	167 40 34.1	Sand	Fine sand
31	24.1	-47 11 52.2	167 40 29.1	Mud	Mud with sand
32	27.6	-47 11 47.6	167 40 28.6	Mud	Mud with sand
33	27.6	-47 11 42.7	167 40 28.9	Mud	Mud with sand
34	28.7	-47 11 49.7	167 40 39.2	Mud	Mud with sand
35	34.0	-47 11 44.2	167 40 38.7	Mud	Mud with sand
36	35.2	-47 11 38.4	167 40 38.5	Mud	Mud with sand
37	35.1	-47 11 32.5	167 40 38.1	Mud	Mud with sand
38	35.4	-47 11 26.2	167 40 38.1	Mud	Mud with sand
39	36.5	-47 11 21.0	167 40 39.6	Mud	Mud with sand
40	37.5	-47 11 12.3	167 40 38.7	Mud	Mud with sand
41	38.0	-47 11 6.8	167 40 39.7	Mud	Mud with sand
42	37.2	-47 11 0.0	167 40 39.6	Mud	Mud with sand
43	35.7	-47 10 53.7	167 40 39.3	Mud	Mud with sand
44	29.1	-47 10 47.6	167 40 39.1	Rocky reef	Complex platform
45	33.8	-47 10 41.6	167 40 39.2	Sand	Fine sand
46	34.1	-47 10 35.6	167 40 39.5	Sand	Shell hash
47	35.2	-47 10 29.6	167 40 39.1	Sand	Shell hash
48	34.2	-47 10 23.4	167 40 39.3	Mud	Mud with sand
49	28.1	-47 10 16.2	167 40 38.8	Sand	Fine sand
50	32.2	-47 10 20.7	167 40 34.6	Mud	Mud with sand
51	28.8	-47 11 51.0	167 40 50.0	Sand	Shell hash
52	31.0	-47 11 42.5	167 40 49.2	Sand	Fine sand
53	32.5	-47 11 34.9	167 40 48.7	Sand	Fine rippled sand
54	33.9	-47 11 25.4	167 40 49.1	Sand	Fine sand
55	35.0	-47 11 14.6	167 40 48.7	Sand	Fine rippled sand
56	36.2	-47 11 7.6	167 40 48.9	Sand	Fine rippled sand
57	36.6	-47 10 58.3	167 40 49.8	Mud	Mud with sand
58	36.6	-47 10 51.5	167 40 48.6	Sand	Fine rippled sand
59_1	33.0	-47 10 43.7	167 40 48.0	Rocky reef	Complex platform
59_2	33.0	-47 10 42.6	167 40 49.1	Sand	Coarse sand
060	35.7	-47 10 35.7	167 40 48.5	Sand	Fine sand
061	34.5	-47 10 27.5	167 40 48.8	Mud	Mud with sand
062	27.9	-47 10 20.7	167 40 48.6	Mud	Mud with sand
063	21.6	-47 11 30.4	167 40 29.7	Sand	Sand
064	23.0	-47 11 20.7	167 40 29.1	Sand	Coarse sand
065	10.0	-47 11 19.8	167 40 24.7	Rocky reef	Low-lying ledges and crevices
066	23.8	-47 11 9.8	167 40 29.3	Sand	Coarse sand
067_1	24.7	-47 11 0.5	167 40 29.5	Rocky reef/Soft sediment	Low-lying ledges and crevices
067_2	24.7	-47 11 0.0	167 40 29.6	Sand	Fine sand
068	27.7	-47 10 50.4	167 40 30.0	Rocky reef/Soft sediment	Large boulder
069	28.3	-47 10 41.2	167 40 29.7	Sand	Fine sand
070	18.6	-47 10 35.6	167 40 28.9	Rocky reef/Soft sediment	Large boulder
071	26.2	-47 11 56.0	167 40 58.9	Rocky reef/Soft sediment	Large boulder
072	33.0	-47 11 46.9	167 40 59.2	Sand	Fine sand
073	33.3	-47 11 38.6	167 40 58.9	Sand	Fine sand
074	33.9	-47 11 30.2	167 40 58.5	Sand	Fine sand
075	34.9	-47 11 22.3	167 40 58.4	Sand	Fine sand
076	35.7	-47 11 14.7	167 40 58.0	Sand	Fine rippled sand
077	36.6	-47 11 7.1	167 40 58.7	Sand	Fine sand
078	37.5	-47 11 0.0	167 40 59.3	Sand	Fine rippled sand

Appendix 3, continued.

SiteID	Depth (m)	Latitude	Longitude	Broad habitat	Substratum texture
079	37.9	-47 10 51.0	167 40 58.8	Sand	Fine rippled sand
080	37.8	-47 10 43.9	167 40 57.8	Sand	Fine sand
081	38.3	-47 10 36.2	167 40 58.0	Mud	Mud with sand
082	35.8	-47 10 28.2	167 40 58.8	Mud	Mud with sand
083	30.0	-47 10 20.9	167 40 58.2	Sand	Coarse sand
084	29.6	-47 10 19.3	167 41 8.6	Sand	Coarse sand
085	34.7	-47 10 26.1	167 41 9.1	Mud	Mud with sand
086	36.3	-47 10 32.4	167 41 8.5	Mud	Mud with sand
087	41.4	-47 10 39.1	167 41 8.7	Mud	Mud with sand
088	39.4	-47 10 45.7	167 41 8.9	Sand	Fine sand
089	39.1	-47 10 52.1	167 41 8.4	Sand	Fine sand
090	39.8	-47 10 59.2	167 41 8.7	Sand	Fine sand
091	38.2	-47 11 5.3	167 41 8.5	Sand	Fine sand
092	36.7	-47 11 12.5	167 41 9.2	Sand	Medium sand
093	36.8	-47 11 18.8	167 41 9.3	Sand	Fine rippled sand
094	36.4	-47 11 25.8	167 41 8.9	Sand	Fine sand
095	36.3	-47 11 32.6	167 41 9.5	Sand	Fine sand
096	36.5	-47 11 39.2	167 41 9.5	Sand	Fine sand
097	36.9	-47 11 45.6	167 41 9.3	Sand	Fine sand
098	37.3	-47 11 52.7	167 41 8.7	Sand	Fine sand
099	29.0	-47 11 59.2	167 41 8.7	Rocky reef/Soft sediment	Large boulder
100	27.2	-47 12 5.8	167 41 8.2	Rocky reef	Low-lying ledges and crevices
101	41.0	-47 12 12.7	167 41 7.9	Sand	Fine sand
102	42.3	-47 12 19.6	167 41 9.0	Sand	Fine sand
103	43.2	-47 12 24.9	167 41 9.2	Sand	Fine sand
104	23.5	-47 10 8.4	167 41 18.7	Sand	Fine sand
105	32.3	-47 10 15.5	167 41 18.4	Sand	Sand
106	38.4	-47 10 22.8	167 41 19.0	Mud	Mud with sand
107	28.3	-47 10 30.2	167 41 18.2	Rocky reef/Soft sediment	Large boulder
108	45.7	-47 10 37.7	167 41 18.7	Mud	Mud with sand
109	29.9	-47 10 32.8	167 41 4.7	Rocky reef/Soft sediment	Large boulder
110	42.0	-47 10 45.5	167 41 18.9	Mud	Mud with sand
111	40.6	-47 10 53.4	167 41 18.2	Mud	Mud with sand
112	41.2	-47 11 1.5	167 41 18.8	Sand	Sand
113	23.7	-47 11 9.7	167 41 18.3	Rocky reef	Low-lying ledges and crevices
114	22.7	-47 11 17.1	167 41 18.6	Rocky reef	Low-lying ledges and crevices
115	34.8	-47 11 24.6	167 41 19.5	Rocky reef/Soft sediment	Large boulder
116	37.3	-47 11 31.9	167 41 18.9	Sand	Fine rippled sand
117	38.2	-47 11 39.2	167 41 18.6	Sand	Fine rippled sand
118	40.6	-47 11 56.5	167 41 18.4	Sand	Fine rippled sand
119	42.9	-47 12 4.2	167 41 18.9	Sand	Coarse sand
120	42.7	-47 12 11.4	167 41 19.1	Sand	Fine rippled sand
121	43.8	-47 12 17.8	167 41 18.4	Sand	Fine rippled sand
122	44.0	-47 12 24.5	167 41 18.9	Sand	Fine rippled sand
123	17.5	-47 10 4.5	167 41 28.1	*Estimated: Sand*	
124	34.2	-47 10 11.1	167 41 28.3	*Estimated: Sand*	
125	37.9	-47 10 17.2	167 41 28.0	*Estimated: Mud*	
126	41.2	-47 10 24.3	167 41 27.9	*Estimated: Mud*	
127	44.5	-47 10 38.0	167 41 27.8	*Estimated: Mud*	
128	41.6	-47 10 45.6	167 41 28.4	*Estimated: Mud*	
129	35.4	-47 10 52.8	167 41 27.4	*Estimated: Mud*	
130	39.6	-47 10 59.9	167 41 28.1	*Estimated: Sand*	
131	28.7	-47 11 5.8	167 41 28.3	*Estimated: Sand*	
132	6.0	-47 11 10.3	167 41 27.9	Rocky reef/Soft sediment	Large boulder
133	20.4	-47 11 19.8	167 41 22.4	*Estimated: Rocky reef*	

Appendix 3, continued.

SiteID	Depth (m)	Latitude	Longitude	Broad habitat	Substratum texture
134	23.0	-47 11 29.7	167 41 27.5	Rocky reef	Low-lying ledges and crevices
135	36.1	-47 11 35.9	167 41 28.1	*Estimated: Sand*	
136	37.7	-47 11 42.7	167 41 27.7	*Estimated: Sand*	
137	37.8	-47 11 49.0	167 41 28.2	*Estimated: Sand*	
138	40.0	-47 11 56.3	167 41 28.5	*Estimated: Sand*	
139	40.9	-47 12 4.8	167 41 27.9	*Estimated: Sand*	
140	42.4	-47 12 12.6	167 41 28.1	*Estimated: Sand*	
141	43.0	-47 12 19.4	167 41 28.1	*Estimated: Sand*	
142	43.6	-47 12 24.6	167 41 27.9	*Estimated: Sand*	
143	11.9	-47 11 40.8	167 41 38.0	*Estimated: Rocky reef*	
144	37.6	-47 11 46.6	167 41 37.1	*Estimated: Sand*	
145	39.4	-47 11 53.2	167 41 37.2	*Estimated: Sand*	
146	41.7	-47 11 59.7	167 41 37.4	*Estimated: Sand*	
147	42.1	-47 12 6.2	167 41 37.7	*Estimated: Sand*	
148	42.7	-47 12 12.2	167 41 37.4	*Estimated: Sand*	
149	40.0	-47 12 18.1	167 41 38.2	Rocky reef/Soft sediment	Large boulder
150	46.0	-47 12 24.6	167 41 38.9	*Estimated: Sand*	
151	15.3	-47 11 41.3	167 41 47.6	Rocky reef	Low-lying ledges and crevices
152	32.7	-47 11 47.8	167 41 46.8	*Estimated: Sand*	
153	38.5	-47 11 55.3	167 41 47.2	*Estimated: Sand*	
154	41.8	-47 12 1.7	167 41 47.0	*Estimated: Sand*	
155	41.2	-47 12 7.9	167 41 47.3	*Estimated: Sand*	
158	42.7	-47 12 24.6	167 41 47.3	*Estimated: Rocky reef*	
159	15.8	-47 12 7.4	167 41 56.6	Rocky reef	Low-lying ledges and crevices
160	35.6	-47 12 1.7	167 41 56.5	*Estimated: Rocky reef*	
161	28.8	-47 11 56.2	167 41 57.1	*Estimated: Rocky reef*	
162	15.6	-47 11 50.9	167 41 56.8	Rocky reef	Low-lying ledges and crevices
163	21.7	-47 11 57.9	167 42 3.0	Rocky reef/Soft sediment	Large boulder
164	16.6	-47 09 59.9	167 41 37.2	*Estimated: Rocky reef*	
165	34.2	-47 10 5.8	167 41 37.6	*Estimated: Mud*	
166	38.1	-47 10 11.9	167 41 37.6	*Estimated: Mud*	
167	40.8	-47 10 19.9	167 41 38.0	*Estimated: Mud*	
168	43	-47 10 26.5	167 41 37.6	*Estimated: Mud*	
169	45.0	-47 10 33.3	167 41 37.9	*Estimated: Mud*	
170	36.4	-47 10 41.5	167 41 37.9	Rocky reef	Large boulder
171	41.7	-47 10 48.0	167 41 37.6	*Estimated: Sand*	
172	36.2	-47 10 54.4	167 41 37.2	*Estimated: Sand*	
173	27.5	-47 11 0.6	167 41 37.6	*Estimated: Sand*	
174	7.6	-47 11 6.5	167 41 37.6	*Estimated: Rocky reef*	
175	10.3	-47 09 53.0	167 41 47.9	Rocky reef/Soft sediment	Low-lying ledges and crevices
176	25.3	-47 09 59.4	167 41 47.0	*Estimated: Sand*	
177	37.1	-47 10 6.4	167 41 47.9	*Estimated: Mud*	
178	39.7	-47 10 12.5	167 41 47.3	*Estimated: Mud*	
179	41.1	-47 10 19.7	167 41 47.4	*Estimated: Mud*	
180	42.6	-47 10 26.6	167 41 47.0	*Estimated: Mud*	
181	44.0	-47 10 33.1	167 41 47.2	*Estimated: Mud*	
183	30.7	-47 10 40.7	167 41 46.3	Sand	Sand
186	33.6	-47 10 37.8	167 41 58.5	Sand	Coarse sand
187	39.8	-47 10 30.4	167 41 55.9	Mud	Mud with sand
188	38.8	-47 10 23.6	167 41 57.3	Mud	Mud with sand
189	38.7	-47 10 16.8	167 41 56.0	Mud	Mud with sand
190	38.1	-47 10 10.1	167 41 55.5	Mud	Mud with sand
191	35.4	-47 10 2.8	167 41 55.3	Mud	Mud with sand
192	29.8	-47 09 56.3	167 41 56.6	Mud	Mud with sand
193	20.5	-47 09 49.9	167 41 56.8	Sand	Medium sand
194	6.0	-47 09 43.9	167 41 55.8	Sand	Medium sand

Appendix 3, continued.

SiteID	Depth (m)	Latitude	Longitude	Broad habitat	Substratum texture
195	32.1	-47 10 37.5	167 42 6.4	Mud	Mud with sand
196	35.6	-47 10 28.8	167 42 5.4	Mud	Mud with sand
197	36.6	-47 10 20.5	167 42 5.6	Mud	Mud with sand
198	37.9	-47 10 12.1	167 42 4.8	Mud	Mud with sand
199	24.4	-47 10 4.3	167 42 4.5	Mud	Mud with sand
200	24.7	-47 09 56.2	167 42 6.0	Mud	Mud with sand
201	19.2	-47 09 49.4	167 42 5.4	Mud	Mud with sand
202	10.2	-47 09 42.0	167 42 4.4	Sand	Medium sand
203	27.6	-47 10 40.0	167 42 14.8	Sand	Sand
204	33.0	-47 10 32.3	167 42 15.3	Sand	Sand
205	31.5	-47 10 25.0	167 42 15.2	Sand	Sand
206	37.3	-47 10 15.9	167 42 13.8	Mud	Mud with sand
207	32.7	-47 10 8.3	167 42 15.2	Mud	Mud with sand
208	26.8	-47 09 59.7	167 42 14.4	Mud	Mud with sand
209	28.2	-47 09 51.3	167 42 15.4	Mud	Mud with sand
210	27.7	-47 09 43.1	167 42 15.4	Mud	Silt
211	26.0	-47 09 35.5	167 42 14.5	Mud	Mud with sand
212	23.5	-47 10 43.7	167 42 21.3	Sand	Sand
213	32.3	-47 10 39.5	167 42 24.8	Sand	Fine sand
214	34.0	-47 10 30.7	167 42 25.3	Sand	Medium sand
215	28.9	-47 10 22.1	167 42 25.0	Sand	Medium sand
216	33.7	-47 10 11.3	167 42 24.3	Mud	Mud with sand
217	35.5	-47 10 2.7	167 42 24.2	Mud	Mud with sand
218	34.5	-47 09 52.1	167 42 24.0	Mud	Mud with sand
219	31.1	-47 09 44.3	167 42 24.2	Mud	Mud with sand
220	16.9	-47 09 38.5	167 42 25.1	Rocky reef	Low-lying ledges and crevices
221	24.3	-47 10 45.1	167 42 35.1	Sand	Fine sand
222	34.3	-47 10 38.9	167 42 34.0	Sand	Coarse sand
223	39.1	-47 10 31.5	167 42 35.3	Sand	Coarse sand
224	27.6	-47 10 22.1	167 42 34.9	Sand	Sand
225	34.1	-47 10 14.1	167 42 34.9	Mud	Mud with sand
226	35.2	-47 10 5.8	167 42 33.9	Mud	Mud with sand
227	29.2	-47 09 58.0	167 42 34.3	Mud	Mud with sand
228	16.0	-47 09 50.6	167 42 35.8	Rocky reef/Soft sediment	Coarse sand
229	19.1	-47 10 47.6	167 42 44.4	Sand	Fine rippled sand
230	31.6	-47 10 39.5	167 42 44.2	Sand	Coarse sand
231	32.6	-47 10 29.9	167 42 44.1	Sand	Sand
232	31.3	-47 10 19.4	167 42 44.3	Mud	Sand
233	34.0	-47 10 9.1	167 42 43.8	Mud	Mud with sand
234	32.3	-47 10 0.1	167 42 44.8	Mud	Mud with sand
235	18.3	-47 09 50.3	167 42 44.0	Sand	Sand
236	25.4	-47 10 1.5	167 42 54.0	Sand	Sand
237	25.7	-47 10 15.1	167 42 54.2	Sand	Sand
238	31.6	-47 10 23.8	167 42 52.6	Sand	Sand
239	25.3	-47 10 33.8	167 42 53.8	Sand	Fine sand
240	22.8	-47 10 35.6	167 43 0.6	Sand	Sand
241	22.3	-47 10 40.6	167 42 52.6	Sand	Sand
V1	34.3	-47 11.951	167 41.176	Rocky reef	Large boulder
V2	36.3	-47 11.935	167 41.178	Rocky reef/Soft sediment	Large boulder
V3	36.3	-47 11.908	167 41.189	Rocky reef/Soft sediment	Low-lying ledges and crevices
V4	35.8	-47 11.886	167 41.191	Rocky reef/Soft sediment	Low-lying ledges and crevices
V5	35.4	-47 11.476	167 41.331	Rocky reef/Soft sediment	Low-lying ledges and crevices
V7	42.0	-47 12.370	167 41.769	Rocky reef/Soft sediment	Low-lying ledges and crevices

Appendix 3, continued.

SiteID	Depth (m)	Latitude	Longitude	Broad habitat	Substratum texture
V8	39.1	-47 12.309	167 41.787	Rocky reef/Soft sediment	Low-lying ledges and crevices
V9	35.4	-47 12.278	167 41.807	Sand	Sand
V9_2	33.8	-47 12.241	167 41.815	Rocky reef/Soft sediment	Low-lying ledges and crevices
V10	21.3	-47 12.186	167 41.916	Sand	Coarse sand
V11	29.2	-47 12.130	167 41.911	Sand	Sand
V12	29.5	-47 11.903	167 41.921	Sand	Sand
V12_2	30.2	-47 11.792	167 41.856	Sand	Coarse sand
V13	34.0	-47 11.380	167 41.261	Rocky reef/Soft sediment	Large boulder
V14	34.3	-47 11.398	167 41.091	Sand	Sand
V15	34.7	-47 11.356	167 41.131	Rocky reef	Large boulder
V16	35.0	-47 11.272	167 41.087	Rocky reef/Soft sediment	Large boulder
V16_2	35.5	-47 10.901	167 41.428	Rocky reef/Soft sediment	Low-lying ledges and crevices
V17	39.9	-47 10.665	167 41.176	Rocky reef/Soft sediment	Large boulder
V19	-	-47 10.908	167 41.484	Rocky reef/Soft sediment	Large boulder
V20	39.5	-47 10.548	167 41.373	Rocky reef/Soft sediment	Large boulder
V21	30.9	-47 10.558	167 41.339	Sand	Fine rippled sand
V22	31.6	-47 10.529	167 41.260	Sand	Fine sand
V23	10.6	-47 10.540	167 41.092	Sand	Fine sand
V23_2	32.3	-47 10.570	167 41.099	Mud	Mud with sand
V24	37.1	-47 10.609	167 41.086	Mud	Mud with sand
V25	35.9	-47 10.494	167 40.963	Rocky reef/Soft sediment	Large boulder
V26	34.1	-47 10.671	167 40.966	Sand	Coarse sand
V26_2	35.9	-47 10.682	167 41.001	Rocky reef/Soft sediment	Low-lying ledges and crevices
V27	38.1	-47 10.862	167 40.800	Rocky reef/Soft sediment	Large boulder
V28	30.7	-47 10.821	167 40.630	Rocky reef/Soft sediment	Low-lying ledges and crevices

Appendix 4. Particle grain-size distribution (%) and organic content (% ash-free dry weight; AFDW) of sediments from 45 sites across North Arm, Port Pegasus/Pikihatiti. Sediment classifications based on the Folk (1954) sediment textural classes are provided.

Site	Silt & Clay % (< 63 µm)	Very Fine Sand % (63 to < 125 µm)	Fine Sand % (125 to < 250 µm)	Medium Sand % (250 to < 500 µm)	Coarse Sand % (500 µm to < 1 mm)	Very Coarse Sand % (1 to < 2 mm)	Gravel % (≥ 2 mm)	AFDW %	Sediment textural class (Folk 1954)
1	43.1	36.9	16.4	1.9	0.6	0.8	0.3	6.7	muddy sand
2	41.3	43.3	10.4	1.9	0.9	1.0	1.3	6.3	slightly gravelly muddy sand
3	38.5	33.2	23.5	2.7	0.7	1.0	0.5	7.2	muddy sand
4	39.4	37.9	17.0	1.5	0.8	0.7	2.7	7.1	slightly gravelly muddy sand
5	36.2	40.9	12.5	2.1	1.5	1.4	5.3	5.9	gravelly muddy sand
6	5.1	4.5	15.8	21.2	42.9	10.5	< 0.1	2.2	sand
7	38.3	45.8	11.8	1.6	1.0	1.1	0.5	6.5	muddy sand
8	21.9	32.1	37.8	7.0	0.4	0.3	0.3	6.3	muddy sand
9	23.0	46.3	15.3	7.4	3.9	1.7	2.4	5.2	slightly gravelly muddy sand
10	35.3	48.9	10.7	1.8	1.4	1.0	0.9	6.6	muddy sand
11	30.8	35.5	27.4	3.8	1.1	0.9	0.5	6.2	muddy sand
12	40.5	42.2	13.5	1.8	0.8	0.7	0.5	7.0	muddy sand
13	6.1	9.4	43.9	37.8	2.6	0.2	< 0.1	4.0	sand
14	14.7	43.8	18.9	17.3	4.6	0.6	0.2	4.0	muddy sand
15	38.7	37.4	15.3	2.4	1.1	1.2	3.8	6.6	slightly gravelly muddy sand
16	11.8	22.1	12.4	19.7	21.8	8.1	4.1	3.8	slightly gravelly muddy sand
17	4.4	5.3	16.0	27.4	20.3	17.2	9.3	1.9	gravelly sand
18	35.6	50.4	10.8	1.6	0.9	0.5	0.3	6.5	muddy sand
19	35.6	48.2	9.3	1.6	1.1	1.0	3.1	6.2	slightly gravelly muddy sand
20	14.5	44.8	28.3	11.2	1.0	0.2	< 0.1	4.4	muddy sand
21	11.8	60.7	16.7	7.9	2.5	0.4	< 0.1	3.2	muddy sand
22	14.7	50.7	32.8	1.6	0.2	< 0.1	< 0.1	4.2	muddy sand
23	28.8	48.1	14.0	2.5	1.8	1.2	3.7	6.0	slightly gravelly muddy sand
24	13.9	54.6	28.9	2.4	0.2	< 0.1	< 0.1	4.0	muddy sand
25	14.5	47.6	34.5	3.2	0.2	< 0.1	< 0.1	5.1	muddy sand
26	6.7	35.9	48.5	7.1	1.6	< 0.1	< 0.1	3.6	sand
27	11.4	38.1	23.9	17.9	8.4	0.3	< 0.1	3.9	muddy sand
28	4.3	0.7	3.1	33.1	31.4	15.9	11.5	2.5	gravelly sand

Appendix 4, continued.

Site	Silt & Clay % (< 63 µm)	Very Fine Sand % (63 to < 125 µm)	Fine Sand % (125 to < 250 µm)	Medium Sand % (250 to < 500 µm)	Coarse Sand % (500 µm to < 1 mm)	Very Coarse Sand % (1 to < 2 mm)	Gravel % (≥ 2 mm)	AFDW %	Sediment textural class (Folk 1954)
29	11.4	62.2	24.6	1.3	0.2	0.2	< 0.1	3.5	muddy sand
30	5.5	59.3	31.8	3.0	0.4	< 0.1	< 0.1	3.1	sand
31	9.3	28.7	15.7	18.5	26.6	0.7	0.6	2.8	sand
32	9.1	53.4	31.1	5.9	0.5	< 0.1	< 0.1	3.8	sand
33	5.9	57.7	32.3	3.9	0.2	< 0.1	< 0.1	3.2	sand
34	6.3	7.7	7.6	17.5	48.0	12.7	0.3	1.9	sand
35	5.1	47.5	40.5	6.8	0.2	< 0.1	< 0.1	3.6	sand
36	4.1	36.1	46.8	11.3	1.6	0.1	< 0.1	3.2	sand
37	9.6	39.0	32.6	15.9	2.6	0.2	< 0.1	3.7	sand
38	6.7	33.7	50.1	9.2	0.3	< 0.1	< 0.1	3.9	sand
39	7.5	32.5	30.7	20.4	8.3	0.4	0.1	3.8	sand
40	3.9	37.9	40.4	13.6	3.8	0.4	< 0.1	2.8	sand
41	3.8	44.8	34.9	10.9	3.2	1.4	0.9	2.1	sand
42	2.3	0.2	0.3	5.0	48.3	40.6	3.3	1.0	gravelly sand
43	5.6	40.1	31.9	13.1	4.1	3.2	2.1	3.0	gravelly sand
44	4.6	39.1	44.0	10.6	1.5	0.1	< 0.1	2.4	sand
45	5.4	38.1	47.9	5.9	2	0.2	0.4	2.8	sand

Appendix 5. Taxa and site level occurrence, as detected through microscopic analysis, present in benthic grab samples from 45 sites across North Arm, Port Pegasus/Pikihatiti. Total abundance data represent the total number of specimens in all 45 samples.

Phylum	Class (Subclass/Infraclass)	Order (Suborder)	Family	Genus	Species	Common name	Total Abund.	Grab sites where present
Porifera	Calcarea	Leucosolenida	Sycettidae	*Sycon*	Unclassified	Glass sponge	1	17
	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Sponge	1	9
Cnidaria	Anthozoa	Actiniaria	Actiniidae	*Anthopleura*	*aureoradiata*	Mud flat anemone	1	2
	Anthozoa	Pennatulacea	Virgulariidae	*Virgularia*	*gracillima*	Sea pen	2	10
	Anthozoa	Unclassified	Unclassified	Unclassified	Unclassified	Anemone	5	1, 16-17,19
Platyhelminthes	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Flat worm	4	17
Nemertea	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Probiscus worm	35	2, 4, 6-7, 10, 15-17, 23, 28, 31-32, 34, 37-38
Nematoda	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Nematode	1520	1-37, 39, 41-45
Sipuncula	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Peanut worm	13	7, 9, 15, 17, 34, 39
Mollusca	Aplacophora	Chaetodermatida	Limifossoridae	Unclassified	Unclassified	Aplacophoran	5	5, 10, 19
	Bivalvia	Anomalodesmata	Thraciidae	*Thracia*	*vegrandis*	Bivalve	1	34
	Bivalvia	Anomalodesmata	Thraciidae	Unclassified	Unclassified	Bivalve	1	12
	Bivalvia	Cardiida	Cardiidae	*Pratulum*	*pulchellum*	Purple cockle	1	2
	Bivalvia	Cardiida	Psammobiidae	*Gari*	*convexa*	Pink sunset shell	7	16, 21, 35, 40, 42
	Bivalvia	Cardiida	Psammobiidae	Unclassified	Unclassified	Sunset clam (juv.)	2	34
	Bivalvia	Imparidentia	Lasaeidae	*Arthritica*	*bifurca*	Bivalve	5	5, 24, 29, 32
	Bivalvia	Imparidentia	Lasaeidae	Unclassified	Unclassified	Bivalve	15	22, 24, 32, 34-35, 39, 45
	Bivalvia	Imparidentia	Mactridae	*Scalpomactra*	*scalpellum*	Duck clam	5	13, 35-36, 38, 45
	Bivalvia	Imparidentia	Ungulinidae	*Diplodonta*	*globus*	Bivalve	17	5, 8-9, 11, 14-16, 22-23, 32
	Bivalvia	Imparidentia	Ungulinidae	Unclassified	Unclassified	Bivalve	2	9
	Bivalvia	Limoida	Limidae	*Limatula*	*maoria*	Bivalve	5	6, 9, 16, 34
	Bivalvia	Lucinida	Thyasiridae	*Prothyasira*	*peregrina*	Cleft clam	61	1-5, 7, 9-12, 18-19, 21
	Bivalvia	Mytilida	Mytilidae	*Aulacomya*	*maoriana*	Ribbed mussel	3	17
	Bivalvia	Mytilida	Mytilidae	*Modiolus*	*areolatus*	Hairy mussel	2	17
	Bivalvia	Mytilida	Mytilidae	*Musculus*	*impactus*	Nesting mussel	1	17

Appendix 5, continued.

Phylum	Class (Subclass/Infraclass)	Order (Suborder)	Family	Genus	Species	Common name	Total Abund.	Grab sites where present
	Bivalvia	Nuculanida	Nuculanidae	*Saccella*	*maxwelli*	Bivalve	2	2, 16
	Bivalvia	Nuculida	Nuculidae	*Linucula*	*hartvigiana*	Nut clam	97	2, 4-6, 8-20, 22-25, 27, 30, 33, 39
	Bivalvia	Nuculida	Nuculidae	*Nucula*	*nitidula*	Nut clam	4	1, 14, 22, 31
	Bivalvia	Nuculida	Nuculidae	Unclassified	Unclassified	Nut clam	2	11, 39
	Bivalvia	Ostreida	Ostreidae	Unclassified	Unclassified	Oyster (juv.)	2	17
	Bivalvia	Pectinida	Pectinidae	Unclassified	Unclassified	Scallop (juv.)	1	17
	Bivalvia	Pholadomyoida	Myochamidae	*Hunkydora*	*novozelandica*	Bivalve	2	17, 37
	Bivalvia	Solemyida	Nucinellidae	*Nucinella*	*maoriana*	Small bivalve	92	1-5, 7-13, 15, 18-19, 23, 33, 35
	Bivalvia	Solemyida	Solemyidae	*Solemya*	*parkinsonii*	Awning clam	150	1-5, 7-12, 15-19, 24
	Bivalvia	Venerida	Veneridae	*Venerupis*	*largillierti*	Venus clam	1	16
	Bivalvia	Venerida	Veneridae	Unclassified	Unclassified	Venus clam (juv.)	1	42
	Bivalvia	Unclassified	Unclassified	Unclassified	Unclassified	Bivalve (juv.)	19	3, 9, 13, 17, 21, 24, 26-27, 40, 43
	Gastropoda	Unclassified	Unclassified	Unclassified	Unclassified	Micro snail	8	12, 35, 40, 43
	Gastropoda (Opisthobranchia)	Unclassified	Unclassified	Unclassified	Unclassified	Sea slug	5	1, 17
Annelida	Oligochaeta	Unclassified	Unclassified	Unclassified	Unclassified	Oligochaete worm	329	2, 6, 8-9, 11, 13-17, 20, 22-29, 31-34, 37-40, 42-45
	Polychaeta	Eunicida	Dorvilleidae	Unclassified	Unclassified	Dorvilleid worm	131	1-12, 14-19, 21, 23, 34, 38-39, 43
	Polychaeta	Eunicida	Eunicidae	Unclassified	Unclassified	Eunicid worm	2	2, 17
	Polychaeta	Eunicida	Lumbrineridae	Unclassified	Unclassified	Worm	95	1-5, 7-8, 10-12, 15-18, 23-24
	Polychaeta	Phyllodocida	Chrysopetalidae	Unclassified	Unclassified	Worm	2	17, 42
	Polychaeta	Phyllodocida	Exogoninae	Unclassified	Unclassified	Worm	51	1, 6-10, 13, 15-17, 23, 28, 34, 42
	Polychaeta	Phyllodocida	Glyceridae	Unclassified	Unclassified	Blood worm	4	6, 17, 39
	Polychaeta	Phyllodocida	Goniadidae	Unclassified	Unclassified	Worm	5	1, 4, 7, 10, 25
	Polychaeta	Phyllodocida	Hesionidae	Unclassified	Unclassified	Bristle worm	22	2-5, 7, 15, 17, 21, 28, 42
	Polychaeta	Phyllodocida	Nephtyidae	*Aglaophamus*	Unclassified	Nephtyid worm	27	3-6, 8-9, 14, 16, 18, 20-23, 25, 29-31, 34, 37, 43
	Polychaeta	Phyllodocida	Nereididae	Unclassified	Unclassified	Sand worm	1	9
	Polychaeta	Phyllodocida	Phyllodocidae	Unclassified	Unclassified	Paddle worm	15	1, 6, 9, 11, 17-19, 42
	Polychaeta	Phyllodocida	Polynoidae	Unclassified	Unclassified	Scale worm	1	17

Appendix 5, continued.

Phylum	Class (Subclass/Infraclass)	Order (Suborder)	Family	Genus	Species	Common name	Total Abund.	Grab sites where present
	Polychaeta	Phyllodocida	Sigalionidae	Unclassified	Unclassified	Worm	36	1-5, 7, 9-12, 15, 18, 21, 28, 38, 42-43
	Polychaeta	Phyllodocida	Sphaerodoridae	Unclassified	Unclassified	Sphaerodorid worm	3	17, 37, 40
	Polychaeta	Phyllodocida	Syllidae	Unclassified	Unclassified	Syllid worm	478	1-12, 14-25, 27-34, 37, 39, 42
	Polychaeta	Sabellida	Oweniidae	Unclassified	Unclassified	Sabellid worm	13	8, 10, 12, 18, 21, 27
	Polychaeta	Sabellida	Sabellidae	*Euchone*	Unclassified	Sabellid worm	22	3, 5-7, 11-12, 16, 18, 36-37, 41, 44
	Polychaeta	Sabellida	Sabellidae	Unclassified	Unclassified	Sabellid worm	22	1-3, 5, 7, 9-10, 12, 16-17, 21-22, 37
	Polychaeta	Sabellida	Serpulidae	*Galeolaria*	*hystrix*	Red tube worm	1	17
	Polychaeta	Sabellida	Serpulidae	*Serpula*	Unclassified	Serpulid worm	9	17
	Polychaeta	Spionida	Magelonidae	*Magelona*	Unclassified	Worm	2	16, 20
	Polychaeta	Spionida	Spionidae	*Spiophanes*	*bombyx*	Spionid worm	1	3
	Polychaeta	Spionida	Spionidae	*Spiophanes*	*modedustus*	Spionid worm	37	1, 4, 7, 13-14, 16, 20-21, 25, 27, 29-32, 37-38, 41, 43-44
	Polychaeta	Spionida	Spionidae	*Spiophanes*	Unclassified	Spionid worm	3	14
	Polychaeta	Spionida	Spionidae	*Prionospio*	Unclassified	Spionid worm	300	3-11, 13-18, 20-34, 36-45
	Polychaeta	Spionida	Spionidae	*Spio*	Unclassified	Spionid worm	3	39, 42, 44
	Polychaeta	Spionida	Spionidae	*Aonides*	Unclassified	Spionid worm	4	28
	Polychaeta	Spionida	Spionidae	*Polydora*	Unclassified	Polydorid worm	31	8-9, 11, 14-18, 21-22, 25, 27, 29, 31, 34, 37, 39
	Polychaeta	Spionida	Spionidae	Unclassified	Unclassified	Spionid worm	3	1, 14, 16,
	Polychaeta	Terebellida	Acrocirridae	*Macrochaeta*	Unclassified	Acrocirrid worm	4	17
	Polychaeta	Terebellida	Acrocirridae	Unclassified	Unclassified	Acrocirrid worm	11	17, 34, 42
	Polychaeta	Terebellida	Ampharetidae	Unclassified	Unclassified	Ampharetid worm	7	1, 7, 10, 18, 38
	Polychaeta	Terebellida	Cirratulidae	Unclassified	Unclassified	Cirratulid worm	622	1-12, 14-35, 37-45
	Polychaeta	Terebellida	Flabelligeridae	Unclassified	Unclassified	Flabelligerid worm	14	9, 16-17, 21, 25, 27, 32-33, 37
	Polychaeta	Terebellida	Terebellidae	*Pista*	Unclassified	Terebellid worm	1	6
	Polychaeta	Terebellida	Terebellidae	Unclassified	Unclassified	Terebellid worm	48	4, 6-10, 12, 16-17, 22-23, 27-31, 34, 37, 42-43
	Polychaeta	Terebellida	Trichobranchidae	*Terebellides*	*stroemii*	Trichobranchid worm	1	8

Appendix 5, continued.

Phylum	Class (Subclass/Infraclass)	Order (Suborder)	Family	Genus	Species	Common name	Total Abund.	Grab sites where present
	Polychaeta (Scolecida)	---	Capitellidae	*Barantolla*	*lepte*	Capitellid worm	2	16, 34
	Polychaeta (Scolecida)	---	Capitellidae	*Capitella*	*capitata*	Capitellid worm	1	36
	Polychaeta (Scolecida)	---	Capitellidae	*Heteromastus*	*filiformis*	Capitellid worm	1	1
	Polychaeta (Scolecida)	---	Capitellidae	*Notomastus*	Unclassified	Capitellid worm	82	1-2, 4, 6-8, 10-11, 15, 18-19, 21, 23-25, 27, 29-32, 34, 37, 43
	Polychaeta (Scolecida)	---	Capitellidae	Unclassified	Unclassified	Capitellid worm	3	10, 27, 33
	Polychaeta (Scolecida)	---	Cossuridae	*Cossura*	*consimilis*	Cossurid worm	183	1-5, 7-12, 15, 18-19, 23
	Polychaeta (Scolecida)	---	Maldanidae	Unclassified	Unclassified	Bamboo worm	196	1-5, 7-12, 15-19, 21, 23, 27, 31, 34
	Polychaeta (Scolecida)	---	Opheliidae	*Armandia*	*maculata*	Opheliid worm	19	14, 17, 27, 32-33
	Polychaeta (Scolecida)	---	Opheliidae	*Travisia*	Unclassified	Opheliid worm	1	32
	Polychaeta (Scolecida)	---	Opheliidae	Unclassified	Unclassified	Opheliid worm	56	6, 9, 16, 20, 22-27, 29-31, 34, 37-39, 41-42, 44-45
	Polychaeta (Scolecida)	---	Orbiniidae	*Orbinia*	*papillosa*	Orbiniid worm	1	34
	Polychaeta (Scolecida)	---	Orbiniidae	*Leitoscoloplos*	Unclassified	Orbiniid worm	1	10
	Polychaeta (Scolecida)	---	Orbiniidae	*Scoloplos*	Unclassified	Orbiniid worm	29	20-22, 24-26, 29-31, 34-35, 37, 39, 44-45
	Polychaeta (Scolecida)	---	Orbiniidae	Unclassified	Unclassified	Orbiniid worm	11	4, 14, 16, 27, 32
	Polychaeta (Scolecida)	---	Paraonidae	*Aricidea*	Unclassified	Paraonid worm	92	1, 4-5, 7, 11-14, 16, 18-29, 31-32, 37, 39, 42, 45
	Polychaeta (Scolecida)	---	Paraonidae	Unclassified	Unclassified	Paraonid worm	310	1-12, 15-19, 21-23, 27-28, 31-32, 34, 37-39, 42, 44
	Polychaeta (Scolecida)	---	Scalibregmatidae	Unclassified	Unclassified	Worm	1	16
	Polychaeta (Sedentaria)	---	Chaetopteridae	*Phyllochaetopterus*	*socialis*	Parchment worm	2	17
	Polychaeta (Sedentaria)	---	Chaetopteridae	Unclassified	Unclassified	Parchment worm	1	32
Arthropoda	Hexanauplia (Copepoda)	---	Unclassified	Unclassified	Unclassified	Copepod	29	9, 13, 16-17, 22-24, 26, 29-30, 33-34, 38
	Malacostraca	Amphipoda	Ampeliscidae	*Ampelisca*	Unclassified	Amphipod	6	6, 17, 21, 25
	Malacostraca	Amphipoda	Caprellidae	Unclassified	Unclassified	Skeleton shrimp	2	9, 34
	Malacostraca	Amphipoda	Haustoriidae	Unclassified	Unclassified	Amphipod	93	13, 20, 22, 24-26, 29-33, 35-41, 43-45

Appendix 5, continued.

Phylum	Class (Subclass/Infraclass)	Order (Suborder)	Family	Genus	Species	Common name	Total Abund.	Grab sites where present
	Malacostraca	Amphipoda	Lysianassidae	Unclassified	Unclassified	Amphipod	40	3, 17-18, 20, 24, 30, 33, 35, 41, 44-45
	Malacostraca	Amphipoda	Phoxocephalidae	Unclassified	Unclassified	Amphipod	73	2-3, 6-8, 11-13, 15-18, 20-25, 30-31, 35-41, 43-45
	Malacostraca	Amphipoda	Unclassified	Unclassified	Unclassified	Amphipod	364	1-7, 9-18, 20-30, 32-45
	Malacostraca	Cumacea	Unclassified	Unclassified	Unclassified	Hooded shrimp	276	1-2, 6, 8-14, 20-27, 29-45
	Malacostraca	Decapoda	Axiidae	*Axiopsis*	Unclassified	Ghost shrimp	1	17
	Malacostraca	Decapoda	Callianassidae	*Callianassa*	*filholi*	Ghost shrimp	34	13-14, 20,22, 25-26, 29-30, 32-33, 35-36, 38, 41, 43
	Malacostraca	Decapoda	Donacidae	*Galathea*	Unclassified	Squat lobster	1	9
	Malacostraca	Decapoda	Goneplacidae	*Neommatocarcinus*	*huttoni*	Policeman crab	2	20, 44
	Malacostraca	Decapoda	Majidae	*Eurynolambrus*	*australis*	Triangle crab	1	17
	Malacostraca	Decapoda	Majidae	*Notomithrax*	Unclassified	Camouflage crab	1	17
	Malacostraca	Isopoda	Anthuridae	Unclassified	Unclassified	Sea slater	3	6, 21, 26
	Malacostraca	Isopoda	Gnathiidae	Unclassified	Unclassified	Sea slater	1	8
	Malacostraca	Isopoda	Munnidae	Unclassified	Unclassified	Sea slater	12	9, 16-17, 27, 42
	Malacostraca	Isopoda (Asellota)	Unclassified	Unclassified	Unclassified	Sea slater	9	4, 17, 231
	Malacostraca	Mysida	Unclassified	Unclassified	Unclassified	Mysid shrimp	5	1, 14, 18, 20, 25
	Malacostraca	Nebaliacea	Unclassified	Unclassified	Unclassified	Small crustacean	15	17, 26, 29-30, 33, 37,
	Malacostraca	Tanaidacea	Unclassified	Unclassified	Unclassified	Tanaid shrimp	92	4, 7-9, 11-12, 14, 16, 18, 22-23, 25, 29-34, 36, 38-39, 41-45
	Ostracoda	Myodocopida	Cylindroleberididae	*Parasterope*	*australis*	Ostracod	1	21
	Ostracoda	Myodocopida	Cylindroleberididae	*Parasterope*	*quadrata*	Ostracod	1	17
	Ostracoda	Myodocopida	Philomedidae	*Scleroconcha*	*arcuata*	Ostracod	1	23
	Ostracoda	Unclassified	Unclassified	Unclassified	Unclassified	Ostracod	25	1, 3, 6, 9, 13, 16-17, 25, 33-34, 37-41, 43-45
Bryozoa	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Encrusting bryozoan	8	9, 17, 29, 39-40,
Brachiopoda	Rhynchonellata	Terebratulida	Terebratellidae	*Magasella*	*sanguinea*	Red brachiopod	1	17
	Rhynchonellata	Rhynchonellida	Notosariidae	*Notosaria*	*nigricans*	Ribbed brachiopod	1	17
	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Brachiopod (juv.)	5	3, 9, 17, 23, 40

Appendix 5, continued.

Phylum	Class (Subclass/Infraclass)	Order (Suborder)	Family	Genus	Species	Common name	Total Abund.	Grab sites where present
Hemichordata	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified	Hemichordate	3	16, 42
Echinodermata	Ophiuroidea	Ophiurida	Ophionereididae	*Ophionereis*	*fasciata*	Mottled brittle star	1	17
	Ophiuroidea	Unclassified	Unclassified	Unclassified	Unclassified	Brittle star	3	10, 17, 30
	Holothuroidea	Dendrochirotida	Phyllophoridae	*Pentadactyla*	*longidentis*	Sea cucumber	9	1, 3, 7, 12
	Holothuroidea	Apodida	Synaptidae	*Rynkatorpa*	*uncinata*	Sea cucumber	1	7
	Holothuroidea	Apodida	Chiridotidae	*Taeniogyrus*	*dendyi*	Sea cucumber	1	34
	Holothuroidea	Unclassified	Unclassified	Unclassified	Unclassified	Sea cucumber	1	15
Chordata	Ascidiacea	Unclassified	Unclassified	Unclassified	Unclassified	Sea squirt	15	9, 17, 23, 42
14	**17**	**35**	**75**	**61**	**43**		**6592**	

Appendix 6. Sediment physical and chemical properties and community level macrofauna variables for grab samples in North Arm, Port Pegasus/Pikihatiti. Indices include: Shannon-Weiner diversity index (SWDI), Pielou's evenness index (Evenness), Margalef richness index (Richness), AMBI biotic coefficient (AMBI), M-AMBI ecological quality ratio (M-AMBI) and benthic quality index (BQI).

		Sediments				Macrofauna statistics							
Site	Depth	Organic matter	Redox	Bacterial mat	Odour	Abundance	No. taxa	Evenness	Richness	SWDI	AMBI	M-AMBI	BQI
unit	m	% AFDW	Eh_{NHE}, mV	-	-	No./core	No./core	Stat.	Stat.	Index	Index	Index	Index
1	36.8	6.7	238	No	No	211	30	0.79	5.42	2.69	1.88	0.69	8.81
2	37.0	6.3	268	No	No	268	25	0.73	4.29	2.35	2.39	0.60	8.68
3	36.7	7.2	296	No	No	96	25	0.88	5.26	2.84	1.90	0.68	9.19
4	38.7	7.1	214	No	No	178	26	0.82	4.82	2.68	2.22	0.66	9.54
5	36.0	5.9	345	No	No	175	23	0.72	4.26	2.25	2.42	0.57	7.69
6	32.7	2.2	433	No	No	111	25	0.73	5.10	2.35	2.86	0.58	5.43
7	40.2	6.5	286	No	No	215	30	0.86	5.40	2.92	1.96	0.72	9.67
8	33.3	6.3	365	No	No	102	25	0.86	5.19	2.77	2.70	0.64	5.53
9	35.2	5.2	406	No	No	428	40	0.63	6.44	2.34	2.30	0.66	4.64
10	43.5	6.6	407	No	No	210	29	0.77	5.24	2.58	2.47	0.64	7.50
11	35.6	6.2	343	No	No	118	26	0.87	5.24	2.85	2.44	0.67	7.48
12	39.4	7.0	274	No	No	127	25	0.87	4.95	2.79	1.74	0.68	8.74
13	33.0	4.0	397	No	No	67	17	0.86	3.81	2.43	2.52	0.55	4.92
14	37.1	4.0	372	No	No	271	22	0.68	3.75	2.09	3.83	0.48	5.60
15	40.7	6.6	405	No	No	268	24	0.74	4.11	2.35	2.71	0.58	6.23
16	37.3	3.8	429	No	No	468	40	0.62	6.34	2.28	2.91	0.64	4.95
17	32.8	1.9	343	No	No	332	62	0.83	10.51	3.42	2.37	0.91	5.90
18	43.7	6.5	277	No	No	302	27	0.71	4.55	2.33	2.43	0.61	5.35
19	40.9	6.2	373	No	No	192	16	0.72	2.85	1.99	2.35	0.50	6.63
20	37.6	4.4	438	No	No	89	20	0.82	4.23	2.45	2.16	0.60	7.02
21	34.8	3.2	439	No	No	174	27	0.54	5.04	1.77	2.64	0.52	4.86

Appendix 6, continued.

Site	Depth	Sediments				Macrofauna statistics							
		Organic matter	Redox	Bacterial mat	Odour	Abundance	No. taxa	Eveness	Richness	SWDI	AMBI	M-AMBI	BQI
unit	m	% AFDW	Eh_{NHE}, mV	-	-	No./core	No./core	Stat.	Stat.	Index	Index	Index	Index
22	37.4	4.2	441	No	No	86	24	0.85	5.16	2.71	2.27	0.65	6.30
23	37.2	6.0	370	No	No	218	29	0.72	5.20	2.42	2.59	0.62	7.03
24	37.3	4.0	414	No	No	47	21	0.91	5.19	2.77	1.78	0.65	7.05
25	39.2	5.1	418	No	No	62	24	0.90	5.57	2.86	2.95	0.63	7.17
26	36.1	3.6	428	No	No	15	60	0.86	3.42	2.34	1.50	0.58	7.11
27	36.3	3.9	442	No	No	23	120	0.80	4.60	2.50	3.27	0.56	7.86
28	35.0	2.5	436	No	No	14	50	0.93	3.32	2.46	2.77	0.54	6.55
29	36.2	3.5	429	No	No	22	68	0.90	4.98	2.79	3.05	0.61	7.04
30	35.7	3.1	422	No	No	21	82	0.87	4.54	2.64	1.99	0.64	5.86
31	33.2	2.8	426	No	No	21	200	0.61	3.77	1.86	2.95	0.49	4.94
32	35.5	3.8	430	No	No	23	85	0.89	4.95	2.79	2.87	0.62	7.04
33	35.3	3.2	403	No	No	19	101	0.85	3.90	2.51	2.65	0.58	5.76
34	34.1	1.9	423	No	No	31	187	0.74	5.73	2.53	2.91	0.63	6.70
35	34.7	3.6	370	No	No	15	55	0.82	3.49	2.23	0.55	0.62	7.64
36	37.4	3.2	437	No	No	11	34	0.79	2.84	1.90	0.96	0.55	7.13
37	33.1	3.7	433	No	No	26	157	0.79	4.94	2.59	3.44	0.58	7.47
38	35.1	3.9	437	No	No	19	85	0.78	4.05	2.28	0.91	0.64	7.00
39	32.3	3.8	400	No	No	24	113	0.83	4.87	2.64	2.52	0.63	7.68
40	39.2	2.8	437	No	No	14	60	0.83	3.18	2.20	1.21	0.55	11.75
41	41.5	2.1	422	No	No	14	48	0.90	3.36	2.37	1.58	0.59	4.77
42	37.3	1.0	424	No	No	24	79	0.82	5.26	2.59	2.79	0.61	6.61
43	43.7	3.0	460	No	No	19	59	0.87	4.41	2.56	2.91	0.55	8.94
44	41.9	2.4	417	No	No	18	74	0.81	3.95	2.33	1.13	0.63	7.37
45	40.5	2.8	373	No	No	16	60	0.85	3.66	2.35	1.14	0.62	5.42

Appendix 7. SIMPER analysis of macrofaunal taxa contributing to at least 50% of the similarity within groups c and b (see Figure 26) of the 45 benthic grab samples clustered at 40% similarity. SIMPER analysis based on fourth-root transformed abundance data.

Group c , Average similarity: 54.20%					
Taxa	**Average Abundance**	**Average Similarity**	**Similarity Standard Deviation**	**Contribution %**	**Cumulative %**
Nematoda	2.52	5.8	4.26	10.7	10.7
Cirratulidae	2.04	4.85	4.9	8.94	19.64
Syllidae	1.86	4.48	6.49	8.27	27.91
Paraonidae	1.79	4.17	5.11	7.69	35.6
Maldanidae	1.48	2.94	1.53	5.42	41.02
Amphipoda	1.41	2.87	1.91	5.29	46.31
Dorvilleidae	1.32	2.75	1.88	5.07	51.38
Group b, Average similarity: 52.32%					
Taxa	**Average Abundance**	**Average Similarity**	**Similarity Standard Deviation**	**Contribution %**	**Cumulative %**
Cumacea	1.73	6.19	3.43	11.82	11.82
Amphipoda	1.5	5.3	2.49	10.12	21.95
Prionospio sp.	1.54	5.02	2.88	9.59	31.53
Haustoriidae	1.25	4.19	1.82	8.01	39.55
Nematoda	1.45	4.18	2	7.98	47.53
Cirratulidae	1.37	3.99	2.03	7.63	55.16

Appendix 8. Enrichment Stage (ES) score calculations for each site from the benthic sampling at North Arm, Port Pegasus/Pikihatiti, April 2017. Indices include: total abundance (N), taxa richness (S), Pielou's evenness index (J'), Margalef's diversity index (d), Shannon-Weiner diversity index (SWDI), AMBI biotic coefficient (AMBI), M-AMBI ecological quality ratio (M-AMBI) and benthic quality index (BQI) (see Appendix 2). For further details about how these values were calculated, see Keeley et al. (2012a).

	Raw data									ES equivalents									Variable group weightings:			
																			0.1	0.2	0.7	
Site:	**TOM**	**Redox**	**N**	**S**	**J'**	**d**	**SWDI**	**AMBI**	**M-AMBI**	**BQI**	**TOM**	**Redox**	**N**	**S**	**d**	**SWDI**	**AMBI**	**M-AMBI**	**BQI**	**Organic loading**	**Sediment chemistry**	**Macro-fauna**	**Overall ES**
1	6.7	238	211	30	0.79	5.42	2.6922	1.881	0.68743	8.81	3.1	1.99	2.97	1.9	1.57	1.59	1.96	2.95	1.43	3.1	1.99	2.05	**2.14**
2	6.3	268	268	25	0.73	4.29	2.3474	2.394	0.60056	8.68	2.96	1.72	3.18	1.92	2.02	2.18	2.34	3.42	1.43	2.96	1.72	2.36	**2.29**
3	7.2	296	96	25	0.88	5.26	2.8387	1.902	0.67511	9.19	3.28	1.47	2.3	1.92	1.62	1.34	1.97	3.02	1.43	3.28	1.47	1.94	**1.98**
4	7.1	214	178	26	0.82	4.82	2.681	2.223	0.65592	9.54	3.25	2.2	2.83	1.89	1.77	1.61	2.21	3.12	1.45	3.25	2.2	2.13	**2.26**
5	5.9	345	175	23	0.72	4.26	2.2452	2.42	0.56855	7.69	2.81	1.02	2.81	2.02	2.04	2.36	2.36	3.59	1.55	2.81	1.02	2.39	**2.16**
6	2.2	433	111	25	0.73	5.1	2.3528	2.861	0.57783	5.43	1.28	0.23	2.42	1.92	1.67	2.17	2.69	3.54	2.33	1.28	0.23	2.39	**1.85**
7	6.5	286	215	30	0.86	5.4	2.9247	1.96	0.71972	9.67	3.03	1.56	2.99	1.9	1.58	1.19	2.01	2.78	1.46	3.03	1.56	1.99	**2.01**
8	6.3	365	102	25	0.86	5.19	2.7676	2.697	0.63787	5.53	2.96	0.84	2.35	1.92	1.64	1.46	2.56	3.22	2.28	2.96	0.84	2.2	**2**
9	5.2	406	428	40	0.63	6.44	2.3356	2.304	0.65899	4.64	2.54	0.48	3.58	2.86	1.45	2.2	2.27	3.11	2.77	2.54	0.48	2.61	**2.18**
10	6.6	407	210	29	0.77	5.24	2.5766	2.467	0.637	7.50	3.07	0.47	2.97	1.88	1.62	1.79	2.39	3.22	1.59	3.07	0.47	2.21	**1.95**
11	6.2	343	118	26	0.87	5.24	2.8492	2.441	0.66596	7.48	2.92	1.04	2.48	1.89	1.62	1.32	2.37	3.07	1.59	2.92	1.04	2.05	**1.94**
12	7	274	127	25	0.87	4.95	2.7853	1.739	0.6801	8.74	3.21	1.66	2.54	1.92	1.72	1.43	1.85	2.99	1.43	3.21	1.66	1.98	**2.04**
13	4	397	67	17	0.86	3.81	2.4331	2.52	0.54987	4.92	2.06	0.56	1.99	2.65	2.31	2.04	2.43	3.69	2.61	2.06	0.56	2.53	**2.09**
14	4	372	271	22	0.68	3.75	2.0893	3.828	0.48118	5.60	2.06	0.78	3.19	2.09	2.35	2.63	3.41	4.07	2.25	2.06	0.78	2.86	**2.36**
15	6.6	405	268	24	0.74	4.11	2.3459	2.705	0.57974	6.23	3.07	0.48	3.18	1.96	2.12	2.19	2.57	3.53	1.97	3.07	0.48	2.5	**2.15**
16	3.8	429	468	40	0.62	6.34	2.2847	2.911	0.64246	4.945	1.97	0.27	3.65	2.86	1.45	2.29	2.72	3.19	2.59	1.97	0.27	2.68	**2.13**
17	1.86	343	332	62	0.83	10.5	3.4232	2.368	0.9086	5.902	1.13	1.04	3.36	1.9	1.21	0.34	2.32	1.76	2.11	1.13	1.04	1.86	**1.62**
18	6.5	277	302	27	0.71	4.55	2.3298	2.431	0.6066	5.348	3.03	1.64	3.28	1.87	1.89	2.21	2.37	3.39	2.37	3.03	1.64	2.48	**2.37**
19	6.2	373	192	16	0.72	2.85	1.9873	2.347	0.50277	6.627	2.92	0.77	2.89	2.8	3.05	2.8	2.3	3.95	1.83	2.92	0.77	2.8	**2.41**
20	4.4	438	89	20	0.82	4.23	2.4482	2.161	0.59964	7.017	2.22	0.19	2.24	2.28	2.05	2.01	2.16	3.43	1.71	2.22	0.19	2.27	**1.85**
21	3.2	439	174	27	0.54	5.04	1.7662	2.637	0.5176	4.862	1.72	0.18	2.81	1.87	1.69	3.18	2.52	3.87	2.64	1.72	0.18	2.65	**2.06**
22	4.2	441	86	24	0.85	5.16	2.7148	2.268	0.64775	6.3	2.14	0.16	2.21	1.96	1.65	1.55	2.24	3.17	1.94	2.14	0.16	2.1	**1.72**
23	6	370	218	29	0.72	5.2	2.4183	2.586	0.61999	7.034	2.85	0.8	3	1.88	1.63	2.06	2.48	3.32	1.7	2.85	0.8	2.3	**2.06**

Appendix 8, continued.

	Raw data										ES equivalents									Variable group weightings: 0.1	0.2	0.7	
Site:	TOM	Redox	N	S	J'	d	SWDI	AMBI	M-AMBI	BQI	TOM	Redox	N	S	d	SWDI	AMBI	M-AMBI	BQI	Organic loading	Sediment chemistry	Macro-fauna	Overall ES
24	4	414	47	21	0.91	5.19	2.7655	1.779	0.65282	7.052	2.06	0.4	1.69	2.18	1.64	1.47	1.88	3.14	1.7	2.06	0.4	1.96	**1.66**
25	5.1	418	62	24	0.9	5.57	2.8639	2.946	0.63239	7.165	2.5	0.37	1.93	1.96	1.54	1.3	2.75	3.25	1.67	2.5	0.37	2.06	**1.77**
26	3.6	428	60	15	0.86	3.42	2.3421	1.5	0.58347	7.106	1.89	0.28	1.9	2.97	2.58	2.19	1.67	3.51	1.68	1.89	0.28	2.36	**1.9**
27	3.9	442	120	23	0.8	4.6	2.4954	3.273	0.55636	7.863	2.02	0.15	2.49	2.02	1.87	1.93	2.99	3.66	1.52	2.02	0.15	2.35	**1.88**
28	2.5	436	50	14	0.93	3.32	2.4633	2.772	0.54058	6.545	1.42	0.21	1.74	3.15	2.65	1.98	2.62	3.74	1.85	1.42	0.21	2.53	**1.96**
29	3.5	429	68	22	0.9	4.98	2.7895	3.049	0.60779	7.036	1.85	0.27	2.01	2.09	1.71	1.42	2.83	3.38	1.7	1.85	0.27	2.16	**1.75**
30	3.1	422	82	21	0.87	4.54	2.6383	1.987	0.63717	5.86	1.68	0.33	2.17	2.18	1.89	1.68	2.03	3.22	2.13	1.68	0.33	2.19	**1.77**
31	2.8	426	200	21	0.61	3.77	1.8645	2.948	0.49224	4.937	1.55	0.3	2.93	2.18	2.33	3.01	2.75	4.01	2.6	1.55	0.3	2.83	**2.2**
32	3.8	430	85	23	0.89	4.95	2.7931	2.869	0.62235	7.037	1.97	0.26	2.2	2.02	1.72	1.42	2.69	3.3	1.7	1.97	0.26	2.15	**1.75**
33	3.2	403	101	19	0.85	3.9	2.5143	2.647	0.57844	5.755	1.72	0.5	2.34	2.39	2.25	1.9	2.53	3.54	2.17	1.72	0.5	2.45	**1.99**
34	1.94	423	187	31	0.74	5.73	2.5335	2.909	0.62827	6.695	1.16	0.32	2.87	1.93	1.51	1.86	2.72	3.27	1.8	1.16	0.32	2.28	**1.78**
35	3.6	370	55	15	0.82	3.49	2.234	0.545	0.61728	7.64	1.89	0.8	1.83	2.97	2.52	2.38	0.96	3.33	1.56	1.89	0.8	2.22	**1.9**
36	3.2	437	34	11	0.79	2.84	1.9033	0.964	0.54618	7.131	1.72	0.2	1.42	3.77	3.06	2.95	1.27	3.71	1.67	1.72	0.2	2.55	**2**
37	3.7	433	157	26	0.79	4.94	2.5864	3.439	0.58304	7.469	1.93	0.23	2.72	1.89	1.72	1.77	3.12	3.52	1.59	1.93	0.23	2.33	**1.87**
38	3.9	437	85	19	0.78	4.05	2.2845	0.914	0.63672	6.997	2.02	0.2	2.2	2.39	2.15	2.29	1.23	3.23	1.71	2.02	0.2	2.17	**1.76**
39	3.8	400	113	24	0.83	4.87	2.6393	2.521	0.62561	7.675	1.97	0.53	2.44	1.96	1.75	1.68	2.43	3.29	1.55	1.97	0.53	2.16	**1.82**
40	2.8	437	60	14	0.83	3.18	2.1983	1.21	0.54808	11.75	1.55	0.2	1.9	3.15	2.77	2.44	1.45	3.7	1.96	1.55	0.2	2.48	**1.93**
41	2.1	422	48	14	0.9	3.36	2.3745	1.579	0.58935	4.769	1.24	0.33	1.71	3.15	2.63	2.14	1.73	3.48	2.7	1.24	0.33	2.51	**1.95**
42	1	424	79	24	0.82	5.26	2.5943	2.786	0.60672	6.61	0.73	0.31	2.13	1.96	1.62	1.76	2.63	3.39	1.83	0.73	0.31	2.19	**1.67**
43	3	460	59	19	0.87	4.41	2.5626	2.908	0.54623	8.939	1.63	-0.01	1.89	2.39	1.95	1.81	2.72	3.71	1.43	1.63	-0.01	2.27	**1.75**
44	2.4	417	74	18	0.81	3.95	2.3327	1.131	0.6268	7.373	1.37	0.38	2.08	2.51	2.22	2.21	1.4	3.28	1.61	1.37	0.38	2.19	**1.75**
45	2.8	373	60	16	0.85	3.66	2.3481	1.139	0.61824	5.421	1.55	0.77	1.9	2.8	2.4	2.18	1.4	3.33	2.34	1.55	0.77	2.34	**1.95**

Appendix 9. Explanation of farm site selection and production scenarios.

Selection of potential farm areas:

Results of the benthic habitat assessment were used to prioritise potential locations for finfish farming operations within the Port Pegasus North Arm area. Circular exclusion 'buffers' were placed around areas of hard substrate or coarse-grained sediments (100 m radius) and areas containing potentially sensitive taxa (250 m radius), identified through sonar imagery and drop-camera transects. Larger exclusion zones were used for potentially sensitive taxa as their exact densities and distributions are unknown.

To provide additional guidance on suitable locations for potential farm sites, an Index of Suitable Location (ISL) for finfish farming was calculated for the entire North Arm area, based on depth and water current data. Results of the ISL analysis indicated that mid-channel areas in Big Ship Passage have the greatest potential for farming, when taking into account exclusion buffers and water depth.

Four potential farming (grow out) areas (c. 10 ha each) were subsequently selected within Big Ship Passage (f1, f2, f3 and f4), along with a smaller smolt growing area (c. 1.3 ha) at the northern coastline. The smolt farm location was selected as it provided some separation from grow-out areas, a feature that was requested during discussions with industry. A maximum of 16 x 160 m circumference pens (two rows of eight pens, c. 20 m spacing between pens) was considered at each of the four potential farming areas. A maximum of 8 x 100 m circumference pens (two rows of four pens, c. 15 m spacing between pens) was considered for the smolt growing area.

Depositional modelling and feed inputs:

As an indicator of likely finfish production capacity within the North Arm area, varying feed input and cage configuration scenarios (a, b, c and d) were modelled across the four farming areas using DEPOMOD v 2.2. Two sets of scenarios were modelled (1 and 2), based on the farming areas operating in a similar way to either low-flow or more dispersive (high-flow[13]) sites within the Marlborough Sounds. This modelling was undertaken to test two very different biophysical response regimes to varying feed inputs.

Maximum feed inputs per pen for each farm area were based on preliminary DEPOMOD assessments for a range of feed inputs for a single pen at each farm area (131–400 t). Feed inputs that resulted in maximum depositional rates of ~6 kg m^{-2} yr^{-1} at the net pen edge were used for DEPOMOD assessments for the low-flow farm scenarios. Feed inputs that resulted in maximum depositional rates of ~13 kg m^{-2} yr^{-1}

[13] This does not suggest that farm sites are 'high-flow', rather that some of the sites may be 'low-flow sites with episodic wave action' which may have a mitigating effect on benthic enrichment. The magnitude of that potential beneficial effect is currently unknown. The use of the high-flow assumption is for comparison purposes only, and does not suggest that the potential effect from waves would be of similar magnitude as high-flow tidal currents in the Marlborough Sounds. The 'high-flow' based scenarios and their associated potential production figures should therefore be interpreted with caution.

at the net pen edge were used for DEPOMOD assessments for the high-flow farm scenarios. These levels of deposition are predicted to result in c. ES 5 conditions if the effects of the farm are similar to low-flow or high-flow farm sites in the Marlborough Sounds region, respectively.

A maximum of 64 grow-out pens (16 pens per area) across the four farm areas were assessed in the modelling, so maximum production was associated with all pens operating at all farms (Table A9.1). Scenarios with lower levels of production were achieved by reducing the number of pens at each of the farm areas. Across the two sets of scenarios (low-flow/high-flow), feed input per pen over a 1-year period varied depending on whether the effects of the farms were modelled as behaving like low-flow or high-flow sites.

As the total number of pens varied across scenarios, the total feed input at each farm area also varied. The feed inputs resulted in scenarios with a range of production levels at each site (~2,800 to 8,000 t production, per annum; Table A9.1). The likely production from each scenario was estimated using a feed conversion efficiency (FCE) ratio of 1.7:1.

For the smolt farm, a feed level of 5% of the total feed input across the four grow-out farms was used across the two sets of scenarios (238 to 680 t per annum; Table 1). Smolt feed was spread evenly across 4, 6 or 8 smolt pens in each scenario, which resulted in feed inputs of 60 to102 t per pen (per annum).

Table A9.1. Farm scenarios and parameters, including feed input per pen (tonnes per annum), number of pens (160 m circumference for grow-out and 100 m circumference for smolt), total feed input and estimated production (tonnes per annum) for the four grow-out areas (f1-f4) and the smolt growing area (s1).

Scenario	**Input parameters**	**Farming area**				**Grow-out**	**Smolt**
		f1	**f2**	**f3**	**f4**	**totals**	**totals**
1a	Feed per pen (tonne)	**131**	**131**	**150**	**225**		64
	Number pens	16	16	16	16	64	8
	Total feed (tonne)	2,100	2,100	2,400	3,600	10,200	510
	Total production (FCE 1.7)	1,235	1,235	1,412	2,118	6,000	
2a	Feed per pen (tonne)	**131**	**131**	**150**	**225**		63
	Number pens	8	10	14	14	46	6
	Total feed (tonne)	1,050	1,312.5	2,100	3,150	7,613	381
	Total production (FCE 1.7)	618	772	1,235	1,853	4,478	
3a	Feed per pen (tonne)	**131**	**131**	**150**	**225**		79
	Number pens	6	8	12	12	38	4
	Total feed (tonne)	787.5	1,050	1,800	2,700	6,338	317
	Total production (FCE 1.7)	463	618	1,059	1,588	3,728	
4a	Feed per pen (tonne)	**131**	**131**	**150**	**225**		60
	Number pens	4	6	8	10	28	4
	Total feed (tonne)	525	787.5	1,200	2,250	4,763	238
	Total production (FCE 1.7)	309	463	706	1,324	2,801	
1b	Feed per pen (tonne)	**175**	**175**	**200**	**300**		85
	Number pens	16	16	16	16	64	8
	Total feed (tonne)	2,800	2,800	3,200	4,800	13,600	680
	Total production (FCE 1.7)	1,647	1,647	1,882	2,824	8,000	
2b	Feed per pen (tonne)	**175**	**175**	**200**	**300**		85
	Number pens	8	10	14	14	46	6
	Total feed (tonne)	1,400	1,750	2,800	4,200	10,150	508
	Total production (FCE 1.7)	824	1,029	1,647	2,471	5,971	
3b	Feed per pen (tonne)	**175**	**175**	**200**	**300**		102
	Number pens	6	8	12	12	38	4
	Total feed (tonne)	1,050	1,400	2,400	3,600	8,450	407
	Total production (FCE 1.7)	618	824	1,412	2,118	4,971	
4b	Feed per pen (tonne)	**175**	**175**	**200**	**300**		79
	Number pens	4	6	8	10	28	4
	Total feed (tonne)	700	1,050	1,600	3,000	6,350	317
	Total production (FCE 1.7)	412	618	941	1,765	3,735	

Appendix 10. DEPOMOD input parameters and settings used to estimate depositional flux to the seabed environment at two locations in North Arm, Port Pegasus/Pikihatiti.

1. Grid Generation	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Smolt site**
Major Grid Size	i=99 @ 14.5 m, j=99 @ 22.4 m (1436 x 2218 m)	i=99 @ 16.7 m, j=99 @ 18.8 m (1650 x 1860 m)	i=99 @ 16.1 m, j=99 @ 16.1 m (1594 x 1594 m)	i=99 @ 16.1 m, j=99 @ 16.1 m (1594 x 1594 m)	i=99 @ 5.6 m, j=99 @ 7.9 m (550 x 780 m)
Minor Grid size	i=99 @ 7 m, j=99 @ 10 m (693 x 990 m)	i=99 @ 5 m, j=99 @ 9 m (495 x 891 m)	i=99 @ 8 m, j=99 @ 7 m (792 x 693 m)	i=99 @ 5 m, j=99 @ 8 m (495 x 792 m)	i=99 @ 3 m, j=99 @ 3 m (297 x 297 m)
Position on grid	i=30, j=18	i=40, j=26	i=22, j=53	i=45, j=11	i=29, j=42
Cage configuration	2 rows of 8	2 rows of 8	2 rows of 8	2 rows of 8	2 rows of 4
Total number cages	4-16	6-16	8-16	10-16	4-8
Spacing between cage centres (m)	70 m	70 m	70 m	70 m	50 m
Depth under cages (m)	15 m	15 m	15 m	15 m	15 m
2. Particle tracking	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Smolt site**
Type of feed release	Continuous	Continuous	Continuous	Continuous	Continuous
Feed loading per cage (scenario)	131(a)-175(b) T yr^{-1}	131(a)-175(b) T yr^{-1}	150(a)-200(b) T yr^{-1}	225(a)-300(b) T yr^{-1}	64-102 T yr^{-1}
Cage dimensions	51 m diameter x 20 m deep	51 m diameter x 20 m deep	51 m diameter x 20 m deep	51 m diameter x 20 m deep	32 m diameter x 20 m deep
Source of velocity data	Hydrodynamic model	Hydrodynamic model	Hydrodynamic model	Hydrodynamic model	Hydrodynamic model
Current depth bins used:	3.0, 11.4, 18, 25.2, 32.4 m above bottom	3.0, 10.7, 18.4, 26.1, 33.8 m above bottom	3.0, 11.2, 19.4, 27.6, 35.8 m above bottom	3.0, 12.2, 19.7, 21.4, 39.8 m above bottom	3.0, 10.0, 17.0, 24.0, 31.0 m above bottom
Current sampling period (min)*	72 min	72 min	72 min	72 min	72 min
Time step used in model (seconds)	4320	4320	4320	4320	4320
Length of velocity record (steps)	619	619	619	619	619
Random walk model	On: Kx=0.1, Ky=0.1, Kz=0.001	On: Kx=0.1, Ky=0.1, Kz=0.001	On: Kx=0.1, Ky=0.1, Kz=0.001	On: Kx=0.1, Ky=0.1, Kz=0.001	On: Kx=0.1, Ky=0.1, Kz=0.001

* Currents sampled from hydrodynamic model