ECOLOGICAL ASSESSMENT FOR A PROPOSED MUSSEL FARM IN THE OUTER FIRTH OF THAMES

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ECOLOGICAL ASSESSMENT FOR A PROPOSED MUSSEL FARM IN THE OUTER FIRTH OF THAMES

View of the proposed marine farm site, Firth of Thames. 14 October 2020.

Contract Report No. 5536

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1. INTRODUCTION

1.1 Background

Te Tumu Kuku partnership (TTK) proposes to establish a mussel farm in the northern Firth of Thames. Wildland Consultants Ltd (Wildlands) was commissioned by TTK to provide an ecological assessment of the proposed site and prepare an assessment of ecological effects to inform the resource consent application.

The proposed farm will lie within an area of *c.*234 hectares located approximately six kilometres to the east of Ponui Island (Figure 1). The site is situated approximately 400 metres to the east of another marine farm site proposed by Ponui Aquaculture Limited that was granted resource consent by Auckland Council in September 2020.

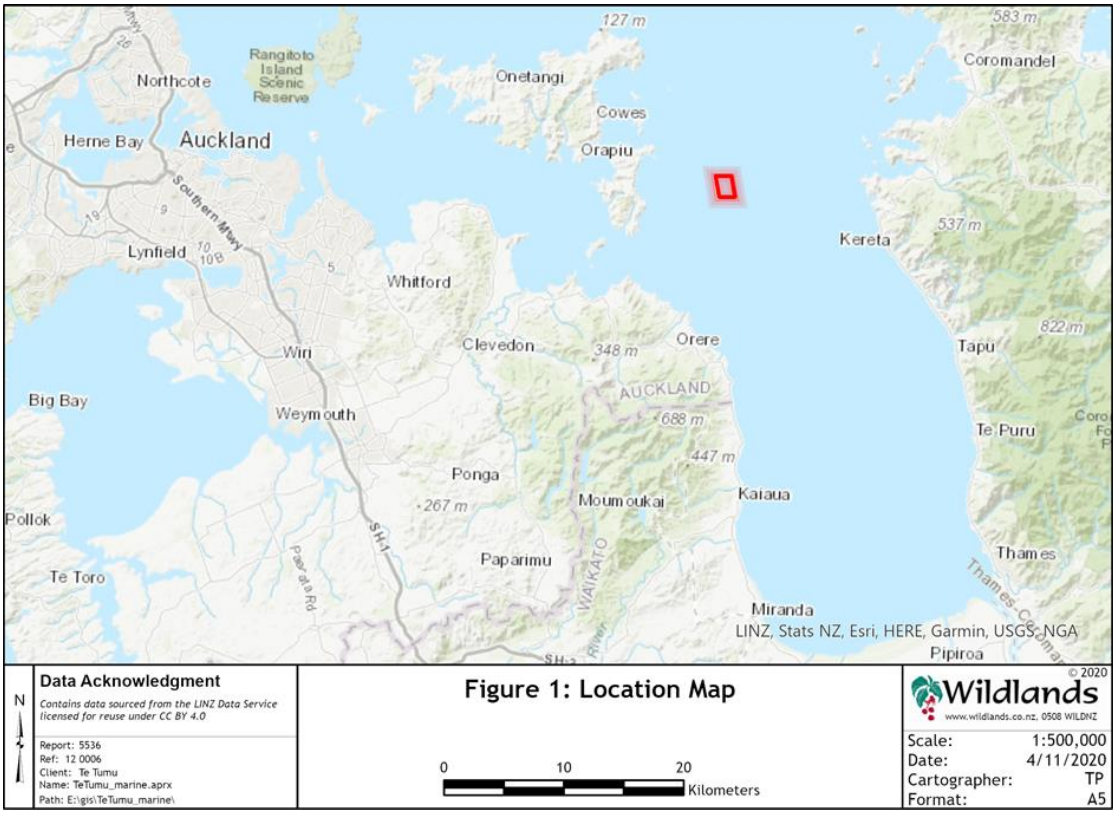


Figure 1: Location Map

Resource consent for a Coastal Permit is required under Section 12 of the Resource Management Act (1991) (RMA), and under the Auckland Unitary Plan (AUP), an application for a new aquaculture activity in the General Coastal Marine (GCM) zone requires consideration as a Discretionary Activity (Rule F2.19.9; A115). These consents require an assessment of effects of the proposed marine farm on marine ecology.

This report presents results of an ecological survey of key seabed physical, chemical and biological characteristics, as well as fundamental water column measurements to characterise the site. In addition to the site characterisation, the report assesses the potential ecological effects of the proposed activity and identifies opportunities for ecological management.

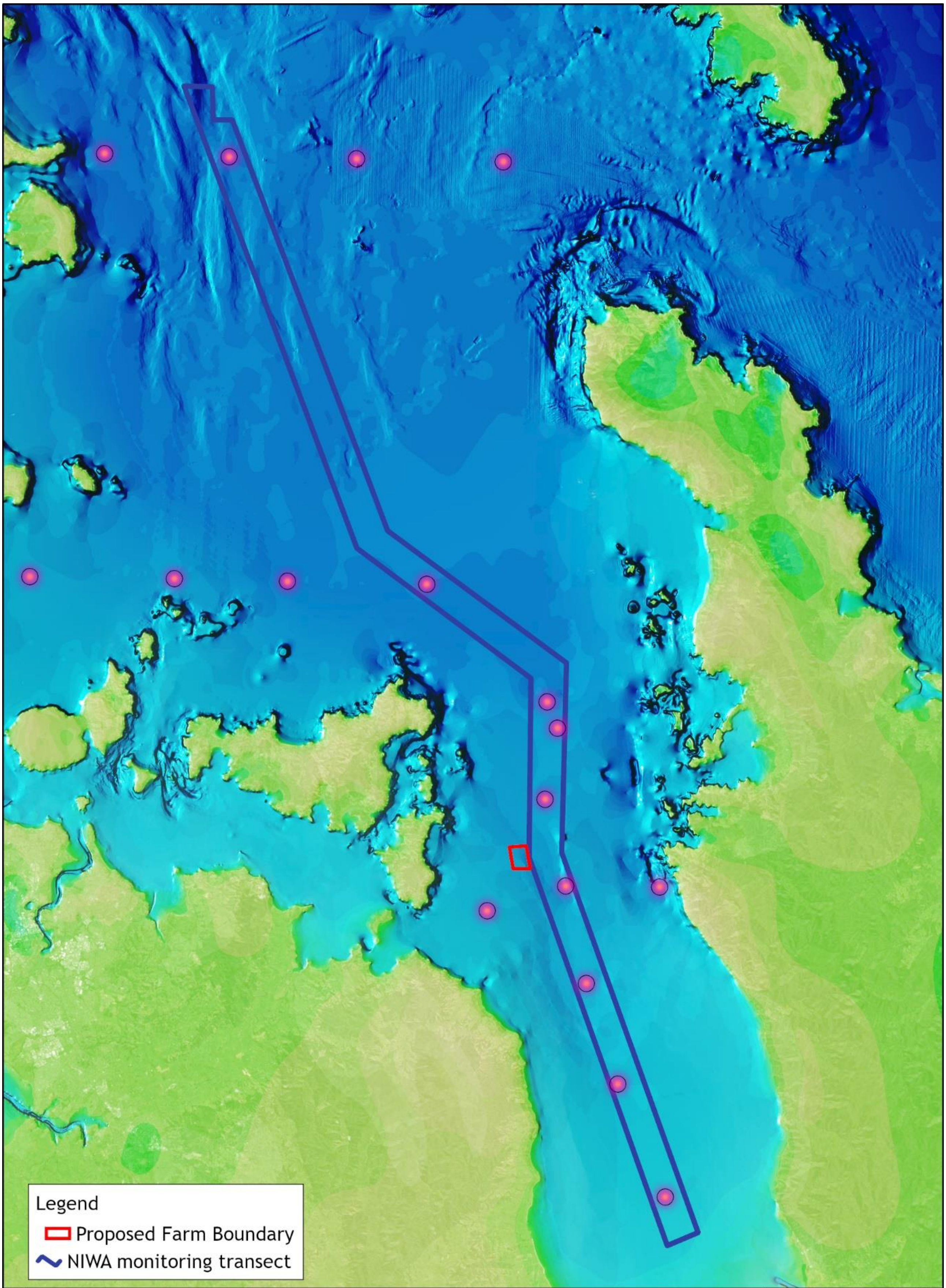
1.2 Geographical and ecological context

The extended Firth of Thames where the proposed site is located is an area of about 360 km^2 extending north of the true Firth to a line roughly from Coromandel township in the east, to Kauri Point on Waiheke Island in the west. The Waihou, Piako and Waitakaruru are the main rivers flowing into the Firth. The land occupying those catchments was covered in indigenous forest prior to human habitation but was progressively cleared for forestry and mining. The dominant land use of the catchment is now agriculture. Following clearance of the forest, fine sediments washing into these rivers from terrestrial sources continue to have adverse effects on ecosystems of the Firth, and subtidal sediments are now mostly composed of mud and silt (Green and Zeldis 2015). Biogeochemical processes in the Firth are influenced by hydrodynamic processes of tidal and wind-driven currents, mixing, and stratification. Nutrient inputs to the Firth come both from land and oceanic sources.

Historically, the Firth of Thames supported dense populations of mussels that were estimated to cover up to 1,300 km^2. However, these beds were almost completely wiped out by dredge fishing during the 1960s (Paul 2012). Although commercial dredge fishing ceased 50 years ago, natural populations have not recovered and only a few small remnant wild mussel beds remain. Currently, the largest populations of mussels in the Firth of Thames are those farmed on longline aquaculture. There have been several studies which have focussed on the restoration of mussel populations. These have assessed the viability of translocating adults and juveniles, primarily from aquaculture, with the aim of establishing self-sufficient populations and recovering lost ecosystem function (e.g. Wilcox *et al*. 2018).

1.3 Previous work in the Firth of Thames

Previous scientific research and monitoring has provided a detailed understanding of how water quality parameters and benthic conditions in the Firth of Thames vary in space and time. Since 1998, NIWA has conducted long term monitoring of a range of parameters at the “Firth” Oceanographic Data Acquisition System (ODAS) mooring to the north of the site, together with repeated spot measurements at a grid of sites within the Firth and the outer Hauraki Gulf (Figure 2). Results of this monitoring have been published in a range of reports and journal articles (Pinkerton *et al.* 2018, Green and Zeldis 2015, Zeldis *et al.* 2015, Hauraki Gulf Forum/Tipaka Moana 2020). This monitoring programme, and other scientific research has taken place in the context of a gradual increase in mussel farm developments in the Firth and has provided a strong evidential basis to validate research from other contexts regarding the localised nature and extent of effects of mussel farms.



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Data Acknowledgment

Data sourced from NIWA (2015a, b)

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Figure 2: Location of NIWA "Firth" long term monitoring ODAS mooring and monitoring grid

0 5 10 Kilometers

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Cartographer:	TP
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1.4 Approach

To assess the potential effects of mussel farming at this site, the field survey focussed on key benthic and water column characteristics including:

- Survey and description of **bathymetry** at the site using sonar to detect any three-dimensional features on the seabed that would indicate the presence of ecologically significant habitats such as rocky or biogenic reefs.
- Sampling of **current speed and direction** during both ebb and flow periods of the tidal cycle to aid our understanding of the likely extent of the depositional footprint and potential effects on phytoplankton distribution from the proposed mussel farm.
- Sampling of **fundamental water column parameters** (depth, turbidity, salinity, pH, water temperature) and **chlorophyll *a* concentration** to help to gauge the capacity of the location to support mussel farming.
- Measurement of key **seabed physical and chemical properties** to aid in predicting likely changes to the seabed as a result of the proposed activity.
- Description of **biological communities** living both on (epifauna) and within (infauna) seabed sediments. This was to identify whether there is any biota of ecological significance present and to enable an assessment of the likely shifts in community structure resulting from the proposed establishment of a mussel farm.

In addition to the survey results, information from previous studies of the ecological effects of aquaculture in the Firth of Thames (and other regions) were reviewed. The synthesis of the survey and desktop work is intended to clearly describe the ecological characteristics of the site, assess the potential ecological effects of the proposed activity, and provide guidance for ecological management following establishment of the farm.

2. METHODS

A field survey was undertaken on 8, 9, and 21 September, and 14 October 2020 by Wildlands ecologists accompanied by the boat skipper (University of Waikato and EZAZ Dive and Environmental Services) aboard the University of Waikato's research vessel Taitimu. All sampling locations were located and recorded using the vessel's plotter (Lowrance HDS Carbon 9).

2.1 Bathymetry and 3-dimensional features

Sonar transects were conducted throughout the wider survey area (hereafter referred to as the site) using a vessel-mounted Lowrance HDS Carbon 9. This instrument has a structure scan transducer which can detect bathymetric features that could indicate the presence of ecologically significant habitat such as rocky or biogenic reefs. Data from the sonar swathing was post-processed using Reefmaster software to produce geo referenced images in ArcMap v9 GIS to depict the seabed bathymetry and to detect the location of any three-dimensional features of interest on the seabed.

2.2 Currents

A vessel-mounted RDI acoustic Doppler current profiler (ADCP) was used to obtain depth-averaged synoptic measurements of current speed and direction at the site during ebb (outgoing) and flood (incoming) phases of the tidal cycle. The ADCP was deployed along two transects traversing the site during an ebb (outgoing) tide from 15:17 to 15:40 (Transect 1), and from 15:54 to 16:14 (Transect 2) on 8 September 2020. A single transect (Transect 3) was conducted during a flood (incoming) tide from 09:51 to 10:17 on 9 September 2020.

2.3 Water column and Chlorophyll *a*

A Van Dorn sampler was used to collect water samples from two locations and at two depths (three metres and 15 metres) within the site) during ebb and flow tidal phases. These water samples were then analysed to obtain measurements of chlorophyll *a* concentration. Chlorophyll *a* concentration is commonly used as a proxy indicator of phytoplankton abundance in marine waters. Each of our measurements provided a snapshot of chlorophyll *a* at one point in time and serve as a verification, and an addition to, existing data drawn from a number of previous larger scale studies.

An Aqua-Troll 600 Multiparameter Sonde was used to collect measurements of depth, turbidity, salinity, pH, and water temperature through the water column at the same locations and times as the chlorophyll samples.

2.4 Grab sampling

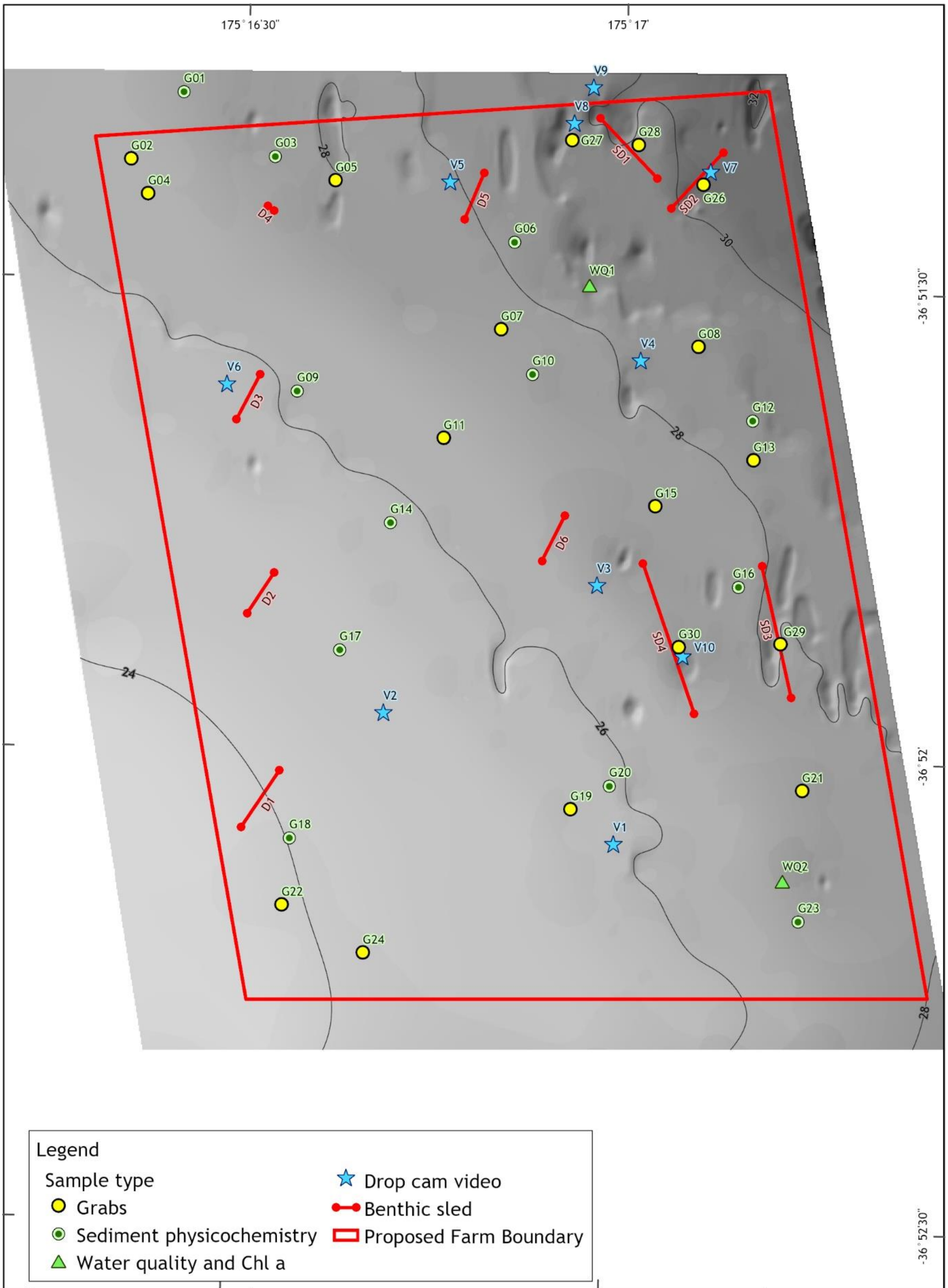
On 8 and 9 September 2021 a benthic Ponar grab (bite area 22.9 × 22 centimetres, volume 8.2 litres) was used to obtain samples to describe infaunal species assemblages at 24 randomly positioned stations throughout the proposed site, and to determine sediment physicochemical characteristics at 12 of those stations. Sampling stations are shown in Figure 3.

On 14 October, an additional four grab samples were obtained targeting areas in the northeastern and eastern portions of the site where shallow depressions or hollows in the seabed were detected by the earlier sonar survey. This was conducted to investigate the benthic faunal species and to confirm the substrate type in the vicinity of these depressions.

2.4.1 Seabed physicochemistry

On recovery of each grab, a photograph was taken of the sediment surface, and sediment texture, appearance, and odour were recorded. Redox potential was measured at a depth of three centimetres below the undisturbed sediment surface of grab samples from 14 grab stations using a YSI Pro Plus meter with combination ORP probe.

Samples requiring chemistry and grain-size analysis in a laboratory were obtained from 12 grab stations distributed throughout the site (Figure 3). A five millilitre subsample of surficial sediment (three centimetres below the sediment surface) was taken from each of the 12 grab samples using a cut-off 12 millilitre syringe for determination of total sulphides. The head-space was minimised and sealed with a stopper, and each sample placed in a sealed bag, chilled on ice, and couriered overnight to the Cawthron Institute for analysis within 24 hours of sampling. A further surficial sample was taken from the top three centimetres of sediment in each of 12 grab samples and transferred to a 500 millilitre plastic jar, kept cool and transported to Hill Laboratories for analysis of sediment grain size, total organic matter, and total organic carbon.



Data Acknowledgment
Data created by Wildland Consultants
Depth contours derived from soundings recorded during sidescan sonar

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Figure 3: Sample positions

0 250 500 m

Datum: WGS84

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Scale:	1:10,000
Date:	11/10/2021
Cartographer:	TP
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2.4.2 Infauna

To describe the assemblage of species living within the sediment at the proposed site, a two litre subsample from each of 28 grab samples was sieved (0.5-mm mesh) on site. The material retained was preserved on the day of collection in 70% ethanol and returned to the laboratory for identification and enumeration of macrofauna living in the sediment. Taxonomic identification and enumeration of infauna was conducted by Charles Bedford (Seahorse Services) and Rod Asher (Biolive Identification Services).

2.4.3 Epifauna

A benthic sled (mouth width 600 millimetres, mesh size four millimetres) was used to sample the assemblage of conspicuous benthic epifauna (large bodied sediment surface-dwelling species) at 10 locations within the proposed site. Tow lengths ranged from approximately 100 metres to 300 metres, with sled tow positions shown in Figure 3. After each sled tow, sediments were rinsed from the sled contents and the large-bodied epifauna retained was identified and enumerated on site. Epifaunal specimens that could not be clearly identified on site were preserved in 70% seawater and returned to the Wildlands offices for positive identification.

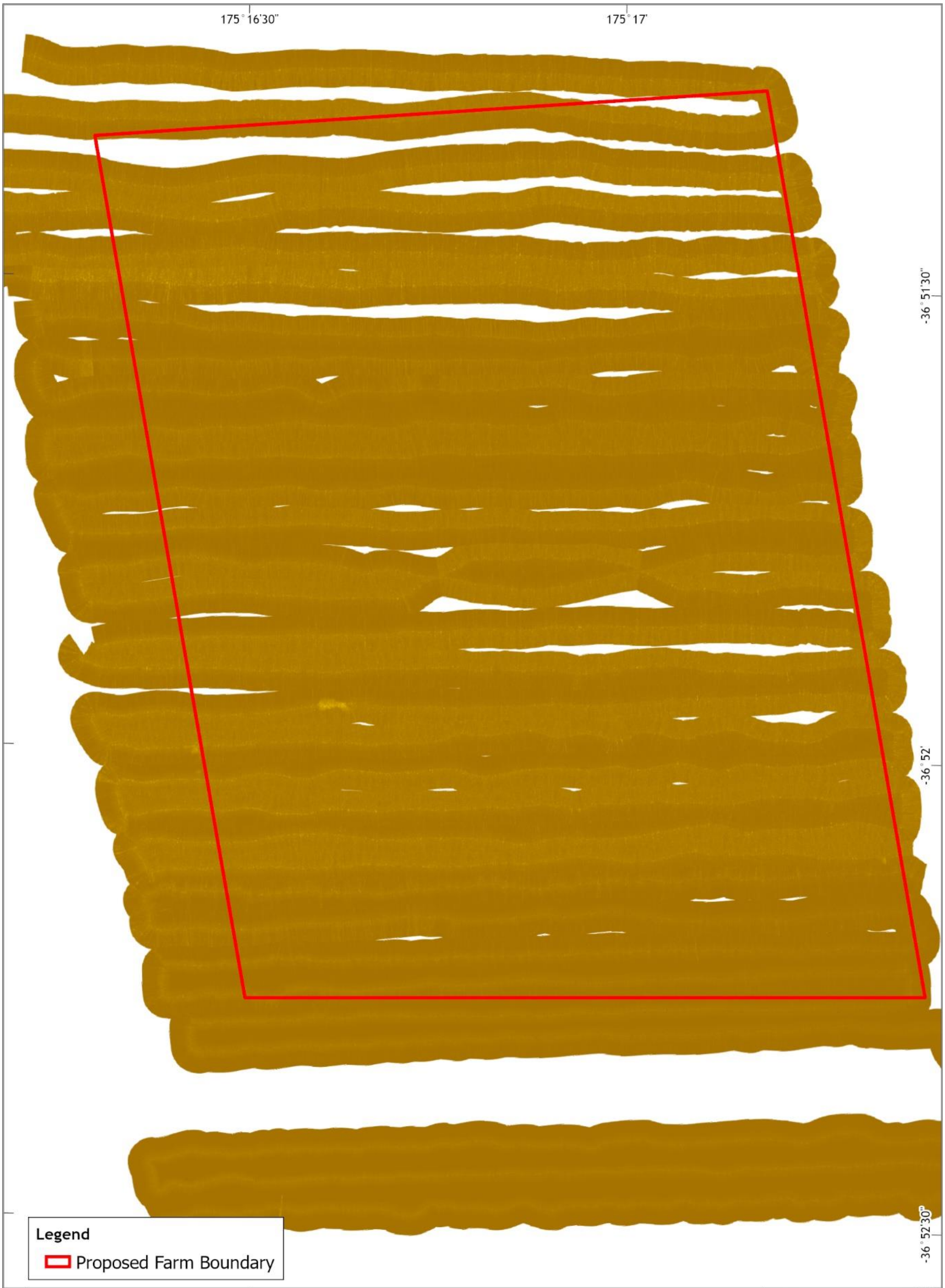
2.4.4 Seabed photographic images

To visually ground truth the sonar data, and contribute to a general description of the seabed habitat, still images were taken from video footage recorded at 10 locations (Figure 3) within the proposed site using a GoPro Hero 8 camera strapped to a video monitor with a light source.

3. RESULTS

3.1 Bathymetry and 3 - dimensional features

The site is located above a relatively featureless muddy seabed that slopes gradually from a water depth of *c.*24 metres in the southwest corner to a maximum depth of *c.*32 metres in the northeast corner. Sidescan swathing did not reveal any prominent three-dimensional features on the seafloor that would indicate the presence of rocky substratum or biogenic reef formations. Sidescan outputs depicting coverage and path of sidescan tracks traversing the site are shown in Figure 4. An analysis of sonar data showed some shallow depressions (maximum depth of trough approximately 0.5 metres) in the seabed in parts of the deeper northeast and east portions of the site, which are visible as a darker grey shade in Figure 3. The seabed in the vicinity of those depressions was subsequently targeted with supplementary sampling to confirm the nature of the substratum and the faunal assemblages. Data output derived from the sonar survey provided a depiction of relative hardness of the substratum across the site (Figure 5). The range of hardness values in Figure 5 represents minor differences in the reflectance characteristics of sonar 'pings' such that the relative 'hardness' is represented by darker green (soft sediment) to lighter green (softest sediment). Sediment sampling results (Section 3.4 of this report) provide ground truthing to accompany the sonar 'hardness' data shown in Figure 5 and confirm that the seafloor throughout the site is comprised of soft sediment.



N	**Data Acknowledgment** *Data created by Wildland Consultants* Report: 5536 Ref: 12 0006 Client: Te Tumu Name: TeTumu_marine.aprx Path: E:\gis\TeTumu_marine\	**Figure 4: Sidescan sonar mosaic** 0 250 500 m Datum: WGS84	© 2021 Wildlands www.wildlands.co.nz, 0508 WILDNZ Scale: 1:10,000 Date: 11/10/2021 Cartographer: TP Format: A4

Note: Blank white patches in Figure 4 represent areas where no reflectance data was recorded.

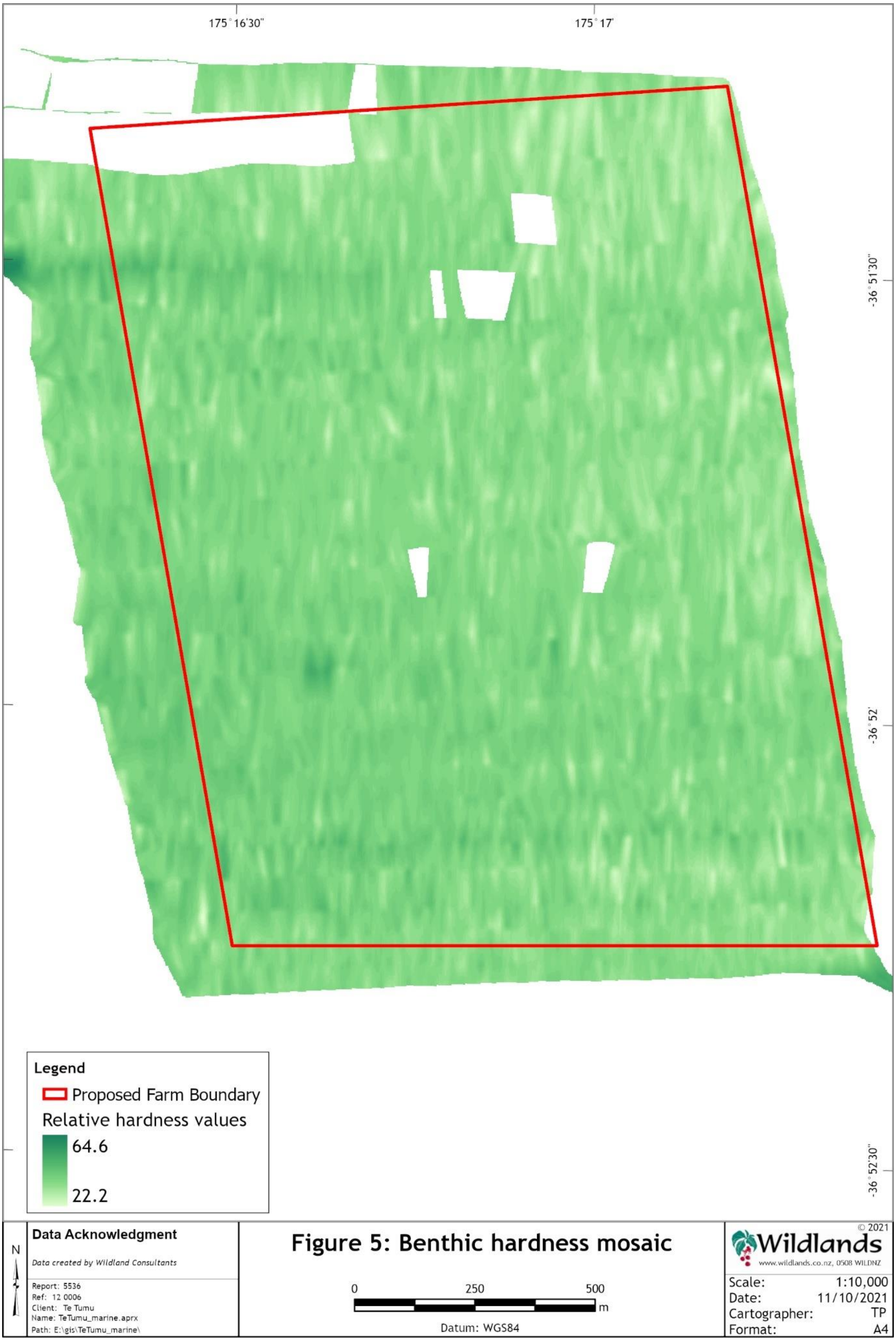


Figure 5: Benthic hardness mosaic

3.2 Currents

Results of measurements from the ADCP transects are shown in Figure 6 and summarised in Table 1. During the latter phase of the ebb tide on 8 September 2020, the depth averaged mean current velocity from two transects was 0.21 $m.s^{-1}$ and 0.18 $m.s^{-1}$ in a direction slightly west of north. During the latter phase of an incoming (flood) tide on 9 September 2020, tidal velocity was 0.13 $m.s^{-1}$ in a direction slightly west of south. These values are consistent with predominantly north-south tidal flows and current speeds in the Firth observed in other studies (Stephens 2003, Bone 2019) and indicate the site is well flushed.

Table 1: Summary of results from ADCP transects.

Transect	Date	Start Time	End Time	Tidal Phase	Mean Speed ($m.s^{-1}$)	Mean Direction (˚)
1	8-9-20	15:17	15:40	Ebb	0.21	351
2	8-9-20	15:40	15:54	Ebb	0.18	355
3	9-9-20	9:55	10:17	Flood	0.13	231

3.3 Water column and Chlorophyll *a*

Turbidity (measured in Nephelometric Turbidity Units, or NTU) was generally lower during the flood tide than ebb tide. This was the case at both water quality stations at near surface and midwater, although at station W2 at midwater the turbidity level was similar to that of the measurements taken during ebb tide.

At both water quality stations, surface waters exhibited slightly lower salinity than midwater on both ebb and flow tidal phases.

In general, the similarity in water column parameter measurements among midwater and surface measurements suggests that the water column is well mixed between those depths.

Chlorophyll *a* concentration at both stations at the surface and midwater were between 0.2 mg/m^3 and 0.3 mg/m^3 at the time of sampling. This occurred during both flood and ebb tidal cycles, except at W2 at midwater during ebb tide where the chlorophyll *a* concentration was below the laboratory detection limit of 0.2 mg/m^3. chlorophyll *a* concentrations were low at all stations relative to values reported for the inner Firth, but within the range previously reported for the outer Firth (Bone 2019, Bury *et al*. 2012, Green and Zeldis 2015). Low levels of chlorophyll *a* (and by proxy, phytoplankton) are also consistent with expectations of phytoplankton abundance in the extended Firth influenced by late winter water column conditions as reported by Zeldis *et al.* (2013).

Table 2: Water column parameters and Chlorophyll a concentration measured at positions W1 and W2.

Station	Date Time	Tidal Phase	Depth (m)	Turbidity (NTU)	Salinity (ppt)	pH	Water Temp (˚C)	Chl a (mg/m^3)
W1	9-9-20 9:38	Flow	3	0.22	33.69	8.47	14.09	0.30
W1	9-9-20 9:39	Flow	15	0.29	33.91	8.48	14.13	0.30
W2	9-9-20 9:51	Flow	3	0.23	33.64	8.51	14.01	0.20
W2	9-9-20 9:49	Flow	15	0.53	33.71	8.50	14.02	0.20
W1	9-9-20 13:56	Ebb	3	0.56	33.37	8.53	14.54	0.20
W1	9-9-20 13:56	Ebb	15	0.43	33.67	8.53	14.15	0.30
W2	9-9-20 13:35	Ebb	3	0.50	33.41	8.49	14.13	0.20
W2	9-9-20 13:35	Ebb	15	0.48	33.72	8.49	14.00	<0.20

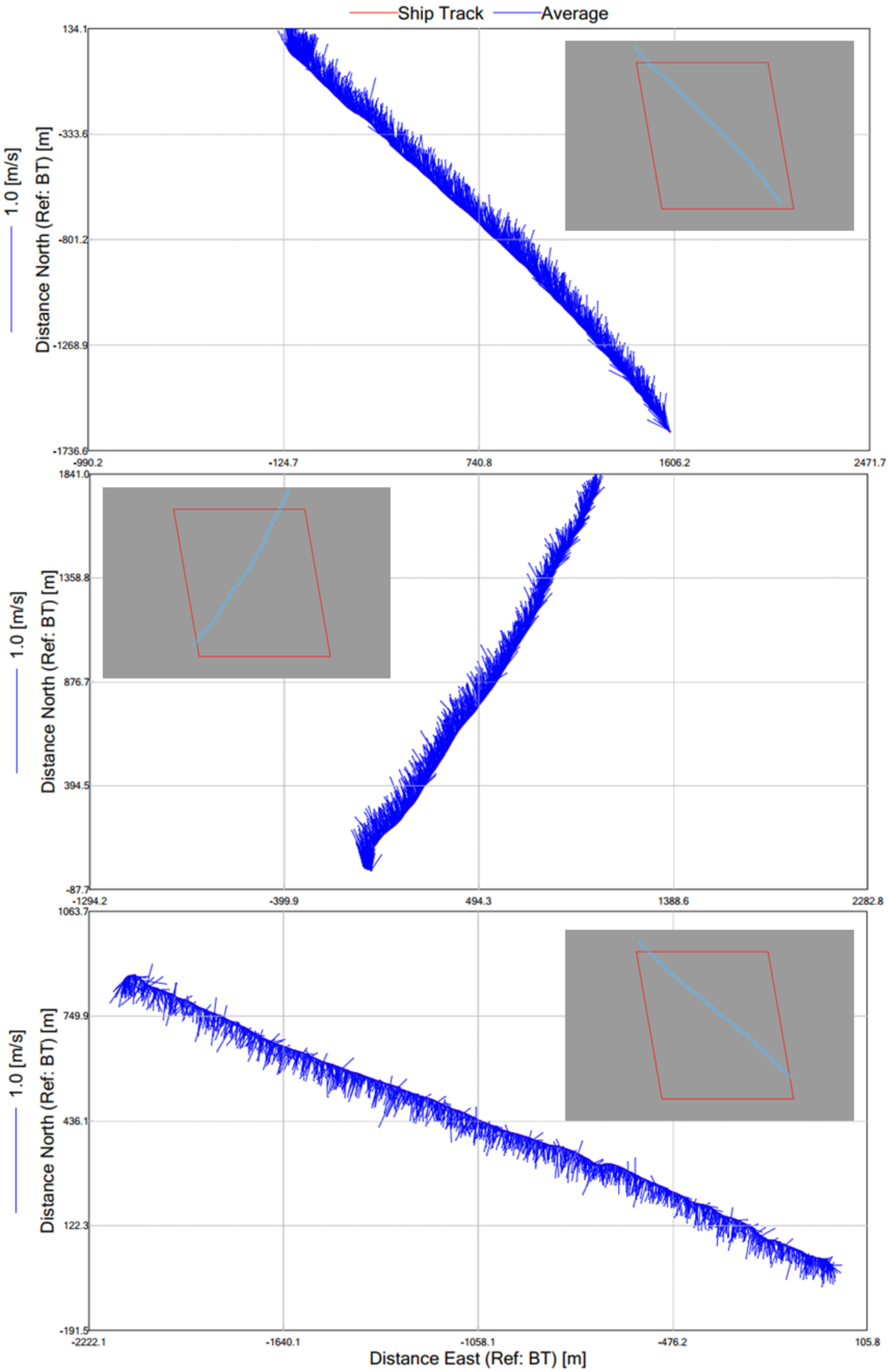


Figure 6: Vessel track and current stick vectors depicting depth-averaged current speed and direction measured in ADCP transects during latter part of ebb tide on 8 September 2020 (top panel, middle panel) and a flood tide (bottom panel) on 9 September 2020. Blue lines in grey insets show vessel path in relation to the red proposed farm boundaries.

3.4 Seabed physicochemistry

3.4.1 Sediment smell and colour

Sediment samples in all grabs appeared to be brown/grey mud. Sediments did not exhibit strong sulphurous or 'rotten egg' smells that would indicate highly organically-enriched sediments. Both of those features (colour and smell) indicated sediments that were well oxygenated. Photographs showing typical grab contents are shown in Plate 1. Photographs of all grab samples are held in the Wildlands archives.

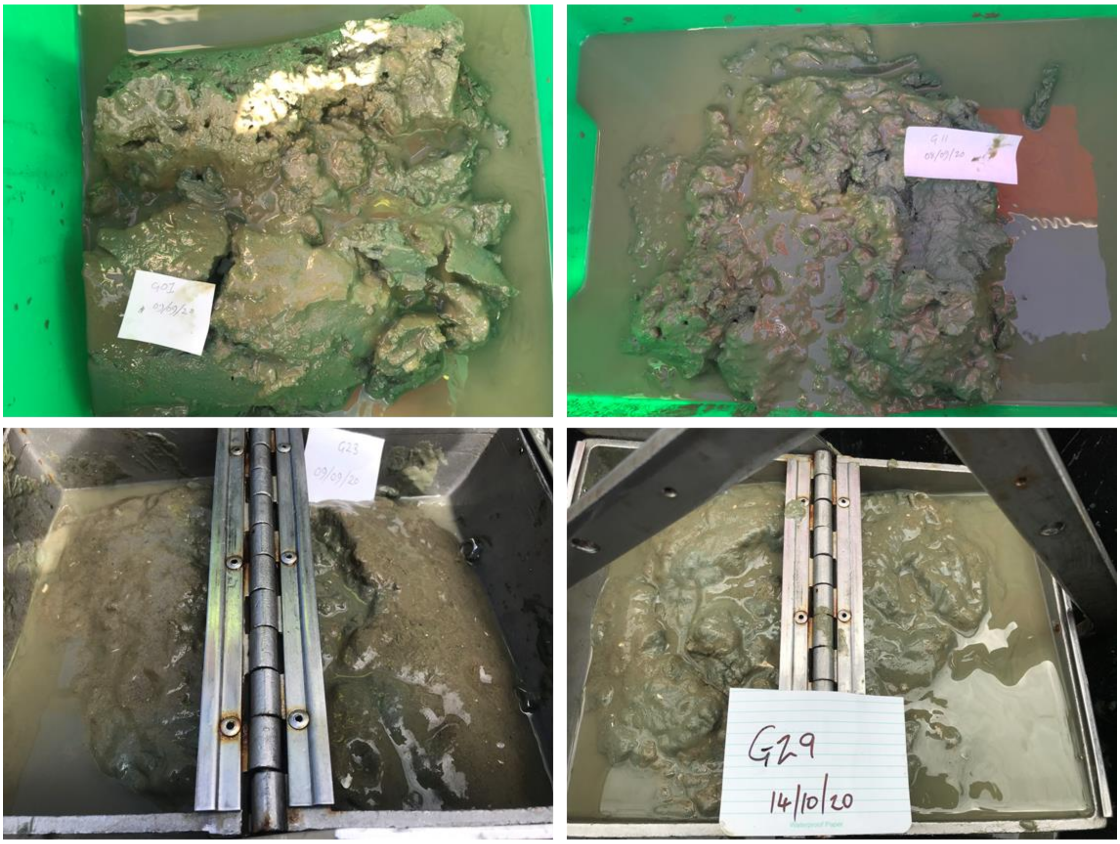


Plate 1: Typical grab contents from grab stations G02 and G11 (above) and intact samples from grab stations G23 and G29 showing very soft sediment surface and 'healthy' brown/grey colouration.

3.4.2 Sediment grain size

Sediments at all grab sample locations were predominantly mud (particle size <63µm comprising between 54% to 70% of the sample), with a significant component of sand (particle size 63-200 µm) and a very small component of mostly calcareous gravel (particle size >2 mm) (Figure 7). The relative proportions of mud and sand showed little variation from grab stations sampled across the wider site. This result reflects the meso estuarine, semi-sheltered nature of the site where sandy mud sediments predominate.

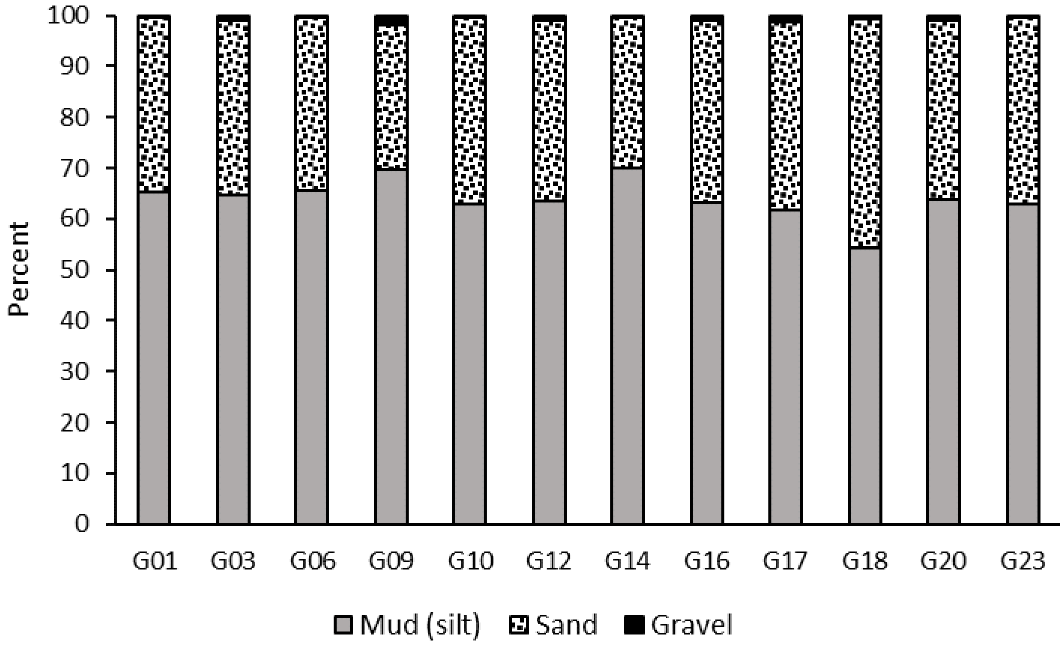


Figure 7: Percentage of each sediment grain size fraction in samples from 12 grab stations distributed throughout the site

3.4.3 Sediment chemistry

Organic matter content of grab samples ranged from 7.6% at grab station G18 to 10.4% at station G16 (Table 3). The mean value of organic matter for all grab stations was 9.5%. The organic content of sediments during a survey conducted at a nearby location in 2018 ranged from 5.5% to 9% (Bone 2019), and the mean value was 7.4% in that survey. Another previous study in the upper Firth of Thames found a mean level between 7 and 8% and a maximum of 11% (Keeley *et al.* 2015). Thus, the average value obtained in the present survey was higher than that measured in some previous studies, but within the range previously measured in the Firth of Thames.

Sulphide concentrations in the sediment were all below the laboratory detection limit of 82 µM except for station 20 where the sulphide concentration was 122 µM (Table 3). The values at all stations are consistent with values reported previously from non-impacted subtidal sites in the Firth of Thames (e.g. Bone 2019) and the Marlborough Sounds (e.g. Morrisey *et al.* 2015). The results indicate well oxygenated sediments with relatively low levels of enrichment. The reading from station 20 is likely to be an anomalous result (i.e. a random outlier).

Values for the redox potential of the sediment ranged from 3.3 millivolts at grab station G10 to 190.1 millivolts at grab station G01 (Table 3). Positive redox values are consistent with low sulphide concentrations and indicate that the sediments are relatively well oxygenated (Zobell 1946).

Table 3: Results of organic content (Total Organic Matter %), sulphide concentration (µM) and Redox potential (mV) in sediment samples from grab stations.

Station	TOM (%)	Sulphides (µM)	Redox ORP (mV)*
G01	9	<82	169.5
G03	10	<82	-
G06	10	<82	190.1
G09	9.6	<82	-
G10	10.1	<82	3.3
G12	10.2	<82	-
G14	9.9	<82	125.6
G16	10.4	<82	-
G17	9.6	<82	60.5
G18	7.6	<82	-
G20	8.5	122	-
G23	9	<82	76.0

* Only the Redox (Eh) readings that were measured in samples from grab stations where % total organic matter and sulphide concentration were measured are presented in the table. Values for redox potential measured in grab samples from a further 8 stations were all within the range of values shown.

3.5 Infauna

A total of 73 taxa were identified from the grab samples (Appendix 1). The mean number of species (taxonomic richness) in grabs ranged from 14 to 30 taxa per sample. The overall average number of taxa across the site was 21. The number of individual animals sampled from each grab (abundance per sample) ranged from 25 to 226, and the average number of individuals per sample was 100.

The most common taxa were polychaete worms from the families Nephtyidae, Cossuridae, Cirratulidae and Sigalionidae, the introduced bivalve *Theora lubrica,* small mobile crustaceans from the orders Tanaidacea and Ostracoda, brittle stars from the family Amphiuridae, and the mud crab *Macropthalmus hirtipes.* All taxa recorded were common and widespread species previously identified in subtidal soft sediment habitats in the Hauraki Gulf and Firth of Thames (e.g. Bone 2019, Brown and Asher 2000, Powell 1936).

The species assemblage found in the four grab samples collected during the supplementary sampling, that targeted the shallow seabed depressions in the northeastern and eastern portions of the site, was very similar to that found at the other 24 grab stations. Of the ten most commonly found taxa sampled throughout the wider site (24 grabs), eight of those were among the most frequently sampled taxa from the supplementary sampling.

3.6 Epifauna

Fourteen species of large-bodied sediment surface-dwelling fauna were found in the dredge tows (Table 4). The most commonly sampled taxa were heart urchin (*Echinocardium cordatum*), red brittle star (*Amphiura rosea*), hermit crab (*Pagurus* sp.), olive shell (*Amalda northlandica*) and spire shell (*Zeacolpus* sp.). All epifauna seen in the dredge samples were common and widespread species previously identified in subtidal soft sediment habitats in the Hauraki Gulf and Firth of Thames (e.g. Bone 2019, Brown and Asher 2000, Powell 1936). Typical examples of benthic sled contents are shown in Plate 2.

Plate 2: Typical examples of contents of benthic sled samples.

Table 4: Large-bodied epifauna in benthic sled samples. F=Frequency, A=Total abundance

Taxa/Species	Common Name	D1	D2	D3	D4	D5	D6	SD1	SD2	SD3	SD4	F	A
Echinocardium cordatum	Heart urchin	21	9	8	8	4	7	4	11	4	15	10	91
Amphiura rosea	Red brittle star	3	2	2	4	1	2	11	2	12	1	10	40
Pagurus sp.	Hermit crab	4	3	3	10	3	1	2	4	4	5	10	39
Amalda novaezelandiae	Olive shell		1	1	3	1	1		1	4	7	8	19
Zeacolpus vittatus.	Spire shell	2			3	2	2	7	1	25	21	8	63
Macropthalmus hirtipes	Mud crab			1		2		4	3	5		5	15
Neilo australis	Bivalve mollusc			1			1		1	2	3	5	8
Pratulum pulchellum	Strawberry cockle		3	3	1	1					1	5	9
Dosinia lambata	Bivalve mollusc		1					1			8	3	10
Pyromaia tuberculata	Spider crab			1						3		2	4
Austrofusus glans	Whelk	1			1							2	2
Notoacmea helmsii	Slipper limpet				2							1	2
Struthiolaria papulosa	Ostrich foot							1				1	1
Dosinia greyii	Bivalve mollusc							1				1	1

Note: D1-D6 represent contents of benthic sled sampling conducted on 9/9/20 and SD1 - SD4 represent benthic sled samples conducted on 14 October 2020.

3.7 Seabed photographic images

The still images of the seabed captured from video footage revealed a soft sediment habitat with visible holes and burrows (Plates 3a and 3 b). The only conspicuous epifauna seen in the video footage were occasional heart urchins (*Echinocardium chordatum*) and spire shells (*Zeacolpus* sp.). The paucity of conspicuous large bodied epifauna recorded in video footage was also reflected in the relatively low numbers of large-bodied epifauna found in benthic sled samples. No hard substratum or biogenic reef structures were seen in any of the video recordings.

(a)

(b)

Plates 3a and 3b: Representative examples of still images of the seabed from Video Transect 2 (a) and Video Transect 5 (b) illustrating the soft sediment habitat. Note the spire shell (*Zeacolpus* sp.) shell visible in (a).

4. ASSESSMENT OF ECOLOGICAL EFFECTS

4.1 Summary of potential effects of mussel farming

This section summarises the potential ecological effects of mussel farming generally, drawing from the wider literature. Ecological effects of the Te Tumu Kuku proposal specifically are then assessed in Section 4.2.

4.1.1 Water column

Within the water column, mussel farms can influence hydrodynamics and water quality. The main effects within the water column include the removal and recycling of nutrients, the removal of plankton (depletion), and the potential for cumulative effects from depletion on the carrying capacity of the system. Mussels consume plankton (mainly phytoplankton) and excrete dissolved nutrients (mostly ammonia-nitrogen, dissolved inorganic nitrogen and dissolved reactive phosphorus) and particulates (faeces and pseudofaeces). Mussel farms generally act as a net sink for nutrients, but can also enhance primary production through excretion (Broekhuizen 2004).

Filtration pressure by mussels is sufficient to potentially alter the composition of the phytoplankton and zooplankton/mesoplankton communities through feeding. While mussel farms remove phytoplankton from the water column, this effect is countered to some extent through excretion by mussels of dissolved nutrients, which facilitates growth and recovery of phytoplankton communities down-current of mussel farms. Although there have been a number of studies examining the question of plankton depletion, the extent to which this occurs and its ecological consequences are still not well understood (Keeley *et al*. 2009). Studies of small marine farms in the Marlborough Sounds did not detect any statistically significant depletion of phytoplankton at distances greater than 80 metres beyond farm boundaries (Ogilvie *et al.* 2000). Evidence from studies in Golden Bay in relation to a larger farmed area (80 hectares) found that phytoplankton levels recovered to within ambient concentrations within 200-500 metres of the farm (Butler 2003). More than eight years of monitoring involving intensive plankton surveys in relation to the Wilson Bay Marine Farming Zone in the Firth did not detect significant effects of mussel farms on plankton communities (Keeley *et al*. 2015). Despite the recognised knowledge gaps, no significant water column related issues have been documented, and this suggests that effects associated with traditional inshore mussel farming practices are minor. Predictions of the extent and intensity of food depletion effects for various proposed large-scale mussel farm developments generally agree that mussel farming can lead to measurable water column effects at a local farm scale, but that significant alteration of ecosystem characteristics would be unlikely.

The inner Hauraki Gulf, including the Firth of Thames, displays a high degree of variability in water column conditions; and this limits the ability to measure changes attributable to existing aquaculture in the region (Keeley *et al*. 2015). In the greater Firth, the availability of key nutrients in the water column (particularly nitrogen) and phytoplankton abundance is mostly driven by larger scale processes such as nutrients provided by riverine discharge, and oceanic upwelling entering the Firth from the seaward end (Zeldis 2013, 2015). This is similar to findings in the Marlborough Sounds, where larger-scale oceanic and climate processes have been found to drive patterns in nutrient availability and primary production to a greater degree than the effects of aquaculture (Zeldis *et al*. 2008).

A recent analysis of long term trends in phytoplankton concentrations (measured as chlorophyll *a*) in the Pelorus Sound (where the proportion of water space occupied by mussel farms is relatively high) found that phytoplankton concentrations in the Sound have declined at some sites since the 1980s, coinciding with the expansion of mussel farming. However, the study found the same phenomena of decline of chlorophyll *a* concentrations around much of the New Zealand coastline, including areas where there are no mussel farms, over the past 20-30 years. The study could not definitively establish a cause for the decline but ruled out any correlation with expansion of the marine farming industry. It also identified a correlation between chlorophyll *a* anomalies and inter-annual fluctuations in river flow, further postulating a possible role for rising sea temperatures as a causative factor (Newcombe and Broekhuizen 2020).

4.1.2 Benthic effects

Potential effects on the seabed can result from the deposition of organic material (e.g. shell debris and encrusting organisms) as they detach from farm structures. This can result in changes to seabed physical properties and sediment chemistry, and to the composition of organisms that make up the benthic community. Where water depth is shallow and current velocities are low, international studies have found that deposition of organic material from mussel farms can lead to organic enrichment of the seabed and a significant adverse effect on benthic communities and biogeochemical processes at the seabed (e.g. Dahlbäck & Gunnarsson 1981). However, numerous studies conducted in New Zealand have not detected any significant adverse effects (Keeley 2009). Seabed effects are greatest directly beneath farm sites, and decline in magnitude with distance. Effects are usually difficult to detect 20-50 metres away from farm structures (author pers. obs. and Keeley 2009). The key factors influencing the magnitude of effects are water depth and current speed. Consequently, the magnitude of effects is very much site-specific and effects are minimised by locating farms in well-flushed areas, and at sites where species and habitats of special value are not present.

It is notable that some changes to the seabed beneath mussel farms can be positive. A recent desktop review by NIWA noted that the deposition of material from mussel farms forms three-dimensional heterogeneous habitats that provide food, shelter, protection, and resources for other marine flora and fauna (including recreationally and commercially valuable fish species such as snapper). These deposits can also help to stabilise bottom sediments (Hartstein and Stevens 2005, Stenton-Dozey and Broekhuizen 2020). In such ‘reefs’ formed beneath mussel farms, overall biodiversity and faunal abundance can be elevated (e.g. Keeley and Morrisey 2013), and the dynamics of biogeochemical processes and nutrient cycling can be altered relative to modified and relatively homogeneous soft sediment habitats (i.e. increased oxygen exchange, nitrate flux, and overall benthic regeneration of nutrients) (Giles *et al.* 2006).

4.1.3 Biosecurity

Marine farms can provide a substrate for the settlement and growth of marine pest species. Marine farming activities, therefore, are potential vectors for the spread of pests and diseases around the country via stock and equipment transfers, boat movements, and the provision of a large area of suitable habitat for fouling organisms (Dodgshun *et al*. 2007). Suspended cultivation methods, and structures and materials used for mussel farming (e.g. ropes, floats), provide habitat for fouling pests and can enable them to proliferate at high densities (Carver *et al*, 2003). From a biosecurity perspective, and for mussel farming in particular, ecological risks arise because an infested farm or other structures or vessels can act as a 'reservoir' for the further spread of the pest. If a pest organism is already present in the new habitat, or is likely to spread there regardless of mussel aquaculture activities, for example via natural dispersal or via non-aquaculture vectors (e.g. recreational vessels), then the incremental risk posed by mussel farm operations is likely to be negligible.

4.1.4 Seabirds

Seabirds, including gulls (*Larus* spp.) and shags (*Phalacrocorax* spp., *Leucocarbo* spp., *Stictocarbo* spp.), associate with mussel farms mostly at reseeding and harvesting time when they may feed on biofouling debris as well as the displaced fish such as spotties (*Notolabus celidotus*) and triplefins (*Forsterygion lapillum*) (Morrisey *et al*. 2006). Spotted shag (*Stictocarbo punctatus punctatus*) and king shag (*Leucocarbo carunculatus*; Threatened-Nationally Endangered) have been observed feeding within farms on occasion and resting on surface buoys; of these two species, spotted shag occurs in the Firth of Thames. Pied shag (*Phalacrocorax varius varius*; At Risk-Recovering) are also present in the local area, and may utilise the marine farm for roosting and foraging. There is some potential risk of entanglement in marine farm ropes for diving birds but such incidents are considered rare.

4.1.5 Marine mammals

Potential effects on marine mammals (seals, dolphins, and whales) relate mainly to habitat modification, entanglement in structures, and habitat exclusion. Marine mammal species most likely to be encountered in the Firth of Thames include common dolphins (*Delphinus delphis*), bottlenose dolphins *(Tursiops truncates),* orca (*Orcinus orca*; Threatened-Nationally Critical), Bryde's whale (*Balaenoptera edeni brydei;* Threatened-Nationally Critical) and various beaked whales (Ziphidae) (DuFresne, 2008). Two other species of whales: southern right whales (*Eubalaena australis*; At Risk-Recovering); and humpback whales (Non-Resident Native - Migrant) could possibly have an occasional seasonal presence (McConnell 2020).

Although cases of entanglement of marine mammals in mussel farming structures are rare, there is a well-known case documenting mortality of a Brydes whale that became entangled in spat lines in the Hauraki Gulf in 1996 (Lloyd 2003). Bryde's whales are found in tropical and sub-tropical waters around the globe and are listed by the International Union for the Conservation of Nature (IUCN) as being of 'least concern' (Cooke *et al.* 2018). However, Bryde's whales are listed as a 'Threatened-Nationally Critical' species (i.e. Threat Status 1) in New Zealand because of their small population size, with fewer than 250 mature individuals nationwide (Baker *et al*. 2019). The Hauraki Gulf supports a resident population of 46 Bryde's whales, and another 159 whales may use the Gulf for part of the year (Hauraki Gulf Forum 2018). Lloyd (2003) outlined concerns regarding the proposed establishment of large offshore marine farms proposed at the time for Hawkes Bay, Bay of Plenty, and other locations where these could interact with seasonal migration patterns of whales.

Stenton-Dozey and Broekhuizen (2020) suggested that provision of haul out sites for New Zealand fur seal (*Arctocephalus forsteri*, Not Threatened) and foraging opportunities for seals, common dolphin and bottlenose dolphin may be considered as a positive ecological effect of mussel farms.

4.1.6 Fisheries

Commercial fishing using trawling and Danish seining is prohibited in the Firth of Thames area, but the outer Firth area is frequently targeted by commercial longline fishers (Hauraki Gulf Forum 2020).

Anecdotal evidence from the Firth of Thames, the Marlborough Sounds, and Tasman Bay indicates that mussel farms are valued by some recreational fishers as sites that attract target species including snapper (*Pagrus auratus*) and kingfish (*Seriola lalandi*).

Concern has been expressed regarding mussel consumption of fish larvae in the zooplankton depleting snapper populations. Broekhuizen *et al.* (2004) modelled the possible effects of a large farm development in the Firth of Thames on survival of snapper eggs and larvae. The model indicated a potential reduction in the number of eggs surviving to age eight days of 2.5-15% within a farm of >2,000 hectares. The authors concluded that it is not possible to reliably predict if a chronic reduction in larval survival would translate into a reduction in spawning stock biomass. Similarly, Newcombe and Broekhuizen (2020) examined consumption of zooplankton by mussel farms in the Marlborough Sounds and concluded that there are too few data on zooplankton in the Sounds to test whether zooplankton communities have been affected by mussel farming.

4.2 Assessment of ecological effects for the proposed Te Tumu Kuku mussel farm

4.2.1 Water column effects

The Te Tumu Kuku site is located in an exposed hydrodynamic setting with a relatively high current regime. The site is exposed daily to tidal currents, and at times residual currents, from a range of directions. This characterisation is supported by the measurements made in this study showing depth-averaged current velocities (*c.*0.2 $m.s^{-1}$) with net movement slightly to the west of north on the ebb tide and slightly to the west of south on the flood tide. Measurements of water column parameters (temperature, pH, Turbidity), at midwater and near the surface were similar, indicating mixing among those portions of the water column. These observations are supported by measurements and modelling of hydrodynamic parameters in previous studies in the Firth of Thames describing current velocities in the extended Firth of between 0.2 to 0.4 $m.s^{-1}$ (e.g. Stephens 2003, Bone 2019).

The dominance of large-scale processes of oceanic and riverine drivers of nutrient and plankton dynamics, and the high potential for mixing of waters within and beyond the immediate vicinity of the farm structures, supports the conclusion that any effects in the water column in the Firth and wider Hauraki Gulf from the proposed mussel farming activity including effects on nutrients and phytoplankton abundance are likely to be no more than minor.

4.2.2 Benthic effects

The seabed at the site is composed of a relatively featureless soft mud habitat inhabited by a suite of faunal species that are common and widespread in the subtidal Firth of Thames and wider Hauraki Gulf. No rocky reef or biogenic reef features were detected on the seabed by sonar swathing, underwater video, or grab and benthic sled sampling conducted during the survey. Shallow hollows or depressions in the seabed in the deeper northeast and east portions of the site were detected by the sonar survey, and supplementary sampling targeting those areas with benthic grab, benthic sled and underwater video confirmed that those zones comprised mud habitat with the same infaunal and epifaunal assemblages as the rest of the site.

Sediments at the site exhibited relatively high total organic content. This suggests that the existing levels of organic deposition in this part of the extended Firth may be relatively high. Benthic fauna, therefore, should be predisposed to organic inputs. The water depths, exposed location of the site, and moderate to high current velocities prevalent in the extended Firth area (0.2-0.4 $m.s^{-1}$) (Stephens 2003) will mitigate potential for enrichment of the seabed via deposition of particulate organic material from the farm.

The benthic characteristics observed at the site reflect the modified nature of the seabed in the area resulting from human activities such as forest clearance, agriculture, and the influence of extensive and intensive commercial dredging of the area for mussels during the 1960s. The dredging activity effectively wiped out dense mussel beds which once covered much of the Firth, and that may have historically existed beneath the proposed Te Tumu Kuku site. Changes to the composition of the benthic species assemblage are likely if a mussel farm is established at the site. Deposition of live mussels, and deposition of shell material and various epibiota to the seabed from the farm structures is likely to form habitat that can provide food, shelter, protection and resources for other marine flora and fauna and help to stabilise bottom sediments. Such habitat created beneath mussel farms can promote oxygen exchange, nitrate fluxes, and overall benthic regeneration (Giles *et al*. 2006, Stenton-Dozey and Broekhuizen 2020). Studies have shown that mussel larvae will preferentially settle on live adult mussels (Wilcox 2017), so the deposition on the seabed could have positive effects in terms of aiding in efforts at restoring the mussel beds in the Firth.

The proposed mussel farm will be located in a well flushed site, in deep water, over a modified muddy seabed with no habitats of particularly significant ecological value. As such, any adverse benthic effects will be no more than minor, and it is likely that there will be a positive effect on the benthos through provision of ecological services including habitat provision, and the stabilising of sediments.

4.2.3 Biosecurity

Due to the high level of vessel traffic in and out of Ports of Auckland and the Hauraki Gulf, there are a number of marine pest species already established in Auckland Harbour and the wider Gulf. The establishment of marine pests at the proposed farm could potentially cause serious detrimental effects to the farming operation itself, the wider aquaculture industry, and to indigenous marine habitats. Marine farming operations, if not correctly managed, can potentially provide suitable habitat for proliferation of pest species and facilitate translocation of pests between farms and coastal areas. It is therefore critical that a comprehensive biosecurity management plan (BMP) is set in place prior to establishment of the marine farm. The careful design of such a plan, and strict adherence to its protocols, will reduce the risks of establishment and spread of marine pests to a level that is negligible. The development of BMPs for marine farming operations is a standard requirement for resource consenting of marine farms around New Zealand, and it is expected that a BMP will be developed for the Te Tumu Kuku farm.

4.2.4 Seabirds

A Ramsar-designated wetland site is located along the southern shore of the Firth of Thames. It is an internationally recognised site comprising about 9,000 hectares of intertidal and coastal margins. The Ramsar site is approximately 25 kilometres from the proposed mussel farm so there is very little risk of effects from the mussel farming activity having any effect on bird species that utilise that area.

Seabirds including shags (Phalacrociracidae), gulls (Laridae), and Australasian gannet (*Morus serrator*; Not Threatened) may congregate around and within the farm for roosting and foraging. Foraging behaviour around farms may be greatest at times of harvesting when invertebrates and small fish are displaced from structures and dispersed in the water column. There is some potential risk of entanglement in marine farm ropes for diving birds but such incidents are considered rare. The black petrel (taiko - *Procellaria parkinsoni*, Threatened-Nationally Vulnerable) is the focus of conservation efforts by the Black Petrel Working Group comprised of fishing interests, iwi environmental groups and government agencies to aid recovery of the bird from its threatened status in the Hauraki Gulf (Hauraki Gulf Forum 2020). The main risk to that bird in the Gulf is from recreational and commercial fishing and there is no evidence of mortalities associated with mussel farming. Flesh-footed shearwater (toanui - *Puffinus carneipes*, Threatened - Nationally Vulnerable) are also vulnerable to fishing bycatch, but aquaculture operations are not implicated as a threat. Overall, the effects on seabirds of establishment of the Te Tumu Kuku farm are considered to be less than minor.

4.2.5 Marine mammals

Although the vast majority of sightings of Bryde’s whales have been seaward of the Firth in the greater Gulf area, there were a few recorded sightings in the extended Firth area from 2000 to 2016. (Ebdon 2017, cited in Hauraki Gulf Forum 2017, and Hauraki Gulf Forum 2020). There was one confirmed mortality of a Brydes whale entangled in marine farm spat catching gear in the outer Hauraki Gulf in 1996, but no records of any such an incident in relation to marine farm structures in the Firth. Seasonal whale migration issues are not likely to be a concern in the extended Firth of Thames as whale migration routes are not recorded to overlap or be close to the proposed marine farm site (Lloyd 2003), and the area is not considered to constitute habitat that is important to migratory marine mammal species (McConnell 2020). On this basis the level of effect on Bryde’s whales and other marine mammals of establishment of the Te Tumu Kuku mussel farm is likely to be less than minor.

4.2.6 Fisheries

Commercial longlining takes place within the extended Firth of Thames in the vicinity of the proposed farm. Following establishment of the farm there will be a small decrease in the total area available for longlining. Considering the estimated area of the extended Firth as defined in Green *et al*. (2015) as 360 km^2, the area of the farm structures (≤ 257 hectares) that would effectively exclude longlining activity includes less than 1% of the nominal area of the extended Firth.

Establishment of the mussel farm at the Te Tumu Kuku site is likely to have positive effects for recreational fishers based on the anecdotal evidence referred to above in Section 4.2.6.

The effects on fisheries (commercial and recreational) from the proposed mussel farm will be less than minor.

5. ENVIRONMENTAL MONITORING

Most mussel farms have no specific environmental monitoring conditions, but in the past, some larger farms have been required to undertake some environmental monitoring. If consent is granted, monitoring may be required as a condition of consent.

The following environmental monitoring is proposed for this site:

- **Marine mammal interactions** – reporting requirements should be set out in a Marine Mammal Management Plan
- **Biosecurity** – observation, reporting and action in accordance with a Biosecurity Management Plan (BMP). A (BMP) should be developed prior to establishment of the mussel farm to minimise on-farm and translocation risks. Useful information including a template to assist in developing a BMP is provided in an Aquaculture Biosecurity Handbook published by the Ministry for Primary Industries and available on MPI's website at: https://www.mpi.govt.nz/dmsdocument/13293/direct

Neither benthic changes, nor phytoplankton depletion, nor other water quality monitoring is justified as:

- The NIWA "Firth" ODAS mooring already provides excellent long term monitoring of a wide range of environmental factors in the Firth, including in the vicinity of the proposed mussel farm.
- The benthic effects of suspended culture mussel farms are well known from the many scientific studies undertaken, including the author's own work. Studies on actual benthic effects from suspended culture mussel farms have consistently found that the effects are generally less than minor a few tens of mettes distance or less beyond farm boundaries.
- Such effects are further reduced at deeper, high flow sites such as this, and are likely to be undetectable above natural background variations beyond the farm boundaries.

- Phytoplankton abundance in the Firth is mainly driven by large-scale oceanic, climatic and riverine processes, and to a greater degree than the effects of aquaculture.
- Due to the relatively strong currents and mixing in the water column at the proposed site, phytoplankton abundance and nutrient levels affected by the mussel farming activity, as water passes through the farm, are likely to quickly return to background levels a short distance from the mussel lines. Any effects are likely to be difficult to detect above background variation beyond the farm boundaries.
- The proposed activity is likely to have a positive restorative function, by replacing some ecosystem services that were lost when the natural biogenic mussel beds of the Firth were extirpated through human activities.

6. CONCLUSION

This report assessed the ecological characteristics of the proposed mussel farm site, including evaluations of:

- Bathymetry.
- Water currents.
- Water column parameters including phytoplankton concentrations.
- Benthic physicochemistry.
- Benthic biological communities.

An important factor in this assessment is the ecological and historical context of the site in the extended Firth of Thames. The modified nature of the seabed from the extirpation of the benthic mussel reefs that once covered much of the Firth of Thames, and the sedimentation originating from early land clearance, means that the addition of the proposed mussel farm is likely to contribute some positive ecological effects to the Firth of Thames environment. Foremost of these potential positive effects are:

- The provision of three-dimensional heterogenous habitats that provide food, shelter, protection, and resources for other marine flora and fauna and help to stabilise bottom sediments.
- Increased overall biodiversity in the water column and faunal abundance on the seabed.
- Provision of a larval source that could contribute to regeneration of mussel beds in the Firth.

On the basis of the available ecological information relating to potential effects at the proposed site, and on the wider marine environment including seabirds, marine mammals and fisheries, the establishment of the proposed Te Tumu Kuku Mussel Farm will not result in significant adverse ecological effects. As the marine farm will also result in some positive ecological effects, the overall level of adverse effects, if any, is likely to be no more than minor.

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INFAUNA IDENTIFIED IN GRAB SAMPLES

Taxa	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18	G19	G20	G21	G22	G23	G24	G26	G27	G29	G30
Anthozoa																												
Edwardsia sp.	1		2										1															
Virgularia gracillima																											1	
Ascidiacea																												
Molgulidae										2									1									
Bivalvia																												
Arthritica bifurca	8					1								1	5			1			1	4		3				1
Borniola sp.				1																								
Dosinia greyi										1												1				1	1	
Dosinia lambata		1	1	1				1	1		1	1	2		1		6		1		1	5		1			1	
Ennucula strangei			2							1	1		3		2		1				2		1		1			2
Linucula hartvigiana	3					3				3			2	2	1							1	1	2				
Mactra ordinaria	1														1													
Musculista senhousia			1											1														
Neilo australis						2						1							2	1				2		1		
Nucula nitidula	2		1		1	1		1		1	1											1					1	
Purpurocardia purpurata															1											1		
Solemya parkinsoni	31	5				1	18	1	2					1		18		5	3	2	5	5	14	25				
Soletellina nitida					1	1																						
Theora lubrica	2	10	18	26	23		20	1	20	26	18	15	2	9	17	8	8	9	23	9	16	3	14	8	4	2	17	3
Thracia sp.		1				14				1	1		1															
Zenatia acinaces																1												
Mysella sp.																										1	5	
Varinucula gallinacea																											1	1
Crustacea																												
Amphipoda Corrophiidae													1															
Amphipoda *Liljeborgia* sp.		1						1	1		1	1	1	1		1	1					2	1	1		3	3	
Amphipoda Phoxocephalidae							1								1													
Amphipoda unidentified			7	2		1		1		1	3	2			2			1		1	1						1	
Amphipoda *Aora sp.*																				1								
Copepoda	1														1									1				
Cumacea	2	1	6	3	1		1	1		2		45	3			2	1			2	2	2	1				3	2
Decapoda *Jaxea novaezelandiae*															1													
Decapoda *Macropthalmus hirtipes*	1	2	2	1		5	1		1	5		3	2	2		1			2	2	1	2	1	3	1	1	1	2
Decapoda Megalopa			3	2		1	1		2	2	1		2		1	1	1	1	1		1	14	1	1				
Decapoda *Pyromaia tuberculata*			1			1								1											1			
Decapoda *Upogebia hirtifrons*																								1				
Isopoda Asellota															1													
Mysidacea										1												1					1	
Ostracod (Cypridinoides reticulata)	18	33	22	18	6	5	10	4	5	5	5	3	5	5	8	26	20	19	11	7	11	25	7	20			1	
Tanaidacea	39	6	12	37	40	41	24		17	10	61	11	14	40	83	19	11	18	12	8	6	6	7	110	1	13	72	2
Echinoidea																												
Echinocardium cordatum	3	1			1	1	2		1							3		2	1	2	1	2	2	1	2		3	3
Gastropoda																												
Eatoniella sp.		2															1											
Opistobranchia												1																
Sigapatella sp.																	1											
Zeacolpus pagoda pagoda			2	1						1			1		2	1			1	1			2					
Zeacolpus sp (juvenile)						1	1	1		3	1														1	1	1	
Zeacolpus vitattus												2			1										2		2	
Scaphopoda																												
Cadulus teliger	9	3	8	4	2	2	3	1	4	2	2		2	8	1		2	3		6		7	4	2			1	
Holothuroidea																												
Heterothyone alba						2									1													
Nemertea	2															1	1								1			
Nematoda	3	1	1	1		1		1								2							2					1
Ophiuroidea																												
Amphiuridae	3	2	4	2		5	2	5	2	2	3	9	10	1	2	4		2	1	1		5	1		2	2	3	3
Platyhelminthes	2																											
Polychaeta																												
Capitellidae			1																							1		
Cirratulidae	5	1	3	8	5	1		1	4	1	3	1	4	2			1	2	10	12	3	11		9	3	5	1	2
Cossuridae										9									13									

Taxa	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18	G19	G20	G21	G22	G23	G24	G26	G27	G29	G30
Cossura sp.	7	4	15	14	11	3	2	11	12		4	8	5	9	9	10	6	5		11	14	7	2	15	3	4	11	3
Exogoninae			1												2						1							
Flabelligeridae													1															
Glyceridae												1																
Hesionidae			1	1				1		1				1	1					1		1						
Lumbrineridae			1		1					2	1			1		4	3	1	1		1			1	1			
Maldanidae				1							1							1										1
Agloaphamus sp.	4	4	3	1	6	6	3	6	4	2	5	4	5	5	2	2	1	3	3	2	1	12	3	2	1	1	2	2
Onuphis aucklandensis									1					1	2		2	1	2		3	1	1	3		1		1
Paraonidae																												
Aricidea sp.			1	1							1		1				1	1	2	1							1	
Pectinariidae		1											1		2													
Phyllodocidae						1					1																	
Pilargiidae								1	2	1	1		3		1		3		3		2		2	2		1		
Polynoidae											1																	
Sigalionidae	2	6	5	5	5	6	7	4	6	1	3	3	13	9	7	9	1		3	7	2	6	8	8	1		5	3
Spionidae																												
Prionospio sp.				1							1				5	1		1		1	4	2		3			1	
Spiophanes kroyeri							1																					
Paraprionospio sp.												1																
Terebellidae		1	1	3	1		1				1			1	4		3							2				
Trichobranchidae																						1						
Richness	**22**	**20**	**27**	**22**	**14**	**24**	**17**	**18**	**17**	**25**	**25**	**18**	**24**	**20**	**30**	**19**	**21**	**18**	**20**	**20**	**21**	**25**	**20**	**24**	**15**	**16**	**25**	**16**
Abundance	**149**	**86**	**125**	**134**	**104**	**106**	**98**	**43**	**85**	**86**	**122**	**112**	**85**	**101**	**168**	**114**	**75**	**76**	**96**	**78**	**79**	**127**	**75**	**226**	**25**	**39**	**140**	**32**

APPENDIX 2

LABORATORY RESULTS

Hill Laboratories
TRIED, TESTED AND TRUSTED

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28 Duke Street Frankton 3204
Private Bag 3205
Hamilton 3240 New Zealand

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Certificate of Analysis

Client:	Wildland Consultants Limited	**Lab No:**	2434537 SPv2
Contact:	Stephen Brown	**Date Received:**	10-Sep-2020
	C/- Wildland Consultants Limited	**Date Reported:**	08-Oct-2020
	PO Box 7137	**Quote No:**	106544
	Te Ngae	**Order No:**	
	Rotorua 3042	**Client Reference:**	
		Add. Client Ref:	Marine Sediments
		Submitted By:	Stephen Brown

Sample Type: Sediment

Sample Name:		G01 09-Sep-2020	G03 09-Sep-2020	G06 09-Sep-2020	G09 09-Sep-2020	G10 09-Sep-2020
Lab Number:		2434537.1	2434537.2	2434537.3	2434537.4	2434537.5
Individual Tests						
Organic Matter	g/100g dry wt	9.0	10.0	10.0	9.6	10.1
Dry Matter of Sieved Sample	g/100g as rcvd	36	36	34	35	35
Ash	g/100g dry wt	91	90	90	90	90
Total Organic Carbon	g/100g dry wt	1.47	1.66	1.62	1.47	1.56
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	0.2	0.9	2.0	0.3	0.3
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	34.4	34.4	28.4	36.7	34.2
Fraction < 63 µm	g/100g dry wt	65.3	64.7	69.6	63.0	65.5

Sample Name:		G12 09-Sep-2020	G14 09-Sep-2020	G16 09-Sep-2020	G17 09-Sep-2020	G18 09-Sep-2020
Lab Number:		2434537.6	2434537.7	2434537.8	2434537.9	2434537.10
Individual Tests						
Organic Matter	g/100g dry wt	10.2	9.9	10.4	9.6	7.6
Dry Matter of Sieved Sample	g/100g as rcvd	31	35	33	35	35
Ash	g/100g dry wt	90	90	90	90	92
Total Organic Carbon	g/100g dry wt	1.68	1.65	1.66	1.57	1.47
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	1.0	0.5	1.2	0.8	0.9
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	35.3	29.6	37.1	45.0	35.9
Fraction < 63 µm	g/100g dry wt	63.6	69.9	61.7	54.3	63.2

Sample Name:		G20 09-Sep-2020	G23 09-Sep-2020			
Lab Number:		2434537.11	2434537.12			
Individual Tests						
Organic Matter	g/100g dry wt	8.5	9.0	-	-	-
Dry Matter of Sieved Sample	g/100g as rcvd	33	32	-	-	-
Ash	g/100g dry wt	92	91	-	-	-
Total Organic Carbon	g/100g dry wt	1.62	1.67	-	-	-
3 Grain Sizes Profile as received						
Fraction >/= 2 mm	g/100g dry wt	1.0	0.4	-	-	-
Fraction < 2 mm, >/= 63 µm	g/100g dry wt	35.2	36.7	-	-	-
Fraction < 63 µm	g/100g dry wt	63.8	62.9	-	-	-

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Sediment

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
Environmental Solids Sample Drying	Air dried at 35°C Used for sample preparation. May contain a residual moisture content of 2-5%.	-	1-12
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation May contain a residual moisture content of 2-5%.	-	1-12
Organic Matter	Calculation: 100 - Ash (dry wt).	0.04 g/100g dry wt	1-12
Dry Matter for Grainsize samples (sieved as received)	Drying for 16 hours at 103°C, gravimetry (Free water removed before analysis).	0.10 g/100g as rcvd	1-12
Ash	Ignition in muffle furnace 550°C, 6hr, gravimetric. APHA 2540 G 23rd ed. 2017.	0.04 g/100g dry wt	1-12
Total Organic Carbon	Acid pretreatment to remove carbonates present followed by Catalytic Combustion (900°C, O2), separation, Thermal Conductivity Detector [Elementar Analyser].	0.05 g/100g dry wt	1-12
3 Grain Sizes Profile as received			
Fraction >/= 2 mm	Wet sieving with dispersant, as received, 2.00 mm sieve, gravimetry.	0.1 g/100g dry wt	1-12
Fraction < 2 mm, >/= 63 µm	Wet sieving using dispersant, as received, 2.00 mm and 63 µm sieves, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12
Fraction < 63 µm	Wet sieving with dispersant, as received, 63 µm sieve, gravimetry (calculation by difference).	0.1 g/100g dry wt	1-12

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 17-Sep-2020 and 08-Oct-2020. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

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Ara Heron BSc (Tech)
Client Services Manager - Environmental

CAWTHRON
The power of science®

10.09.2020 ID 2060

Stephen Brown
Senior Ecologist

Wildlands Consultants Ltd
623 Whananaki North Road
Hikurangi 0181

Dear Stephen

SEDIMENT SULPHIDE RESULTS

Samples were received 10/09/20 in a polybin, packed with ice.

12 sediment samples were tested for sulphide concentration with a sulphide specific electrode on 10/09/2020, using Cawthron protocol 60.102. The samples were prepared for measurement by solubilizing the sediments in a high pH solution containing a chelating agent and an antioxidant. The electrode output was measured by a millivolt (mV) meter and calibrated using sulphide standards. The sulphide standard was checked for purity using a United States Pharmacopoeia method. Results are found in the table below.

Table 1. Sulphide concentrations in sediments.

Sample ID	Sample Concentration in µM
G1	<82
G3	<82
G6	<82
G9	<82
G10	<82
G12	<82
G14	<82
G16	<82
G17	<82
G18	<82
G20	122
G23	<82

Yours sincerely

Fiona Gower
Technical Consultant
Cawthron Institute

Juliette Butler
Technical Consultant
Cawthron Institute

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Certificate of Analysis

Client:	Wildland Consultants Limited	**Lab No:**	2434541 SPv1
Contact:	Stephen Brown	**Date Received:**	10-Sep-2020
	C/- Wildland Consultants Limited	**Date Reported:**	15-Sep-2020
	PO Box 7137	**Quote No:**	106544
	Te Ngae	**Order No:**	
	Rotorua 3042	**Client Reference:**	
		Submitted By:	Stephen Brown

Sample Type: Saline

Sample Name:		Chl 1_3 09-Sep-2020	Chl 1_15 09-Sep-2020	Chl 2_3 09-Sep-2020	Chl 2_15 09-Sep-2020	Chl 3_3 09-Sep-2020
Lab Number:		2434541.1	2434541.2	2434541.3	2434541.4	2434541.5
Chlorophyll a	g/m^3	0.0003	0.0003	0.0002	0.0002	0.0002

Sample Name:		Chl 3_15 09-Sep-2020	Chl 4_3 09-Sep-2020	Chl 4_15 09-Sep-2020		
Lab Number:		2434541.6	2434541.7	2434541.8		
Chlorophyll a	g/m^3	< 0.0002	0.0002	0.0003	-	-

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Saline

Test	Method Description	Default Detection Limit	Sample No
Chlorophyll a	Acetone extraction. Fluorometer. APHA 10200 H (modified) 23rd ed. 2017.	0.0002 g/m^3	1-8

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed on 15-Sep-2020. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

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Kim Harrison MSc
Client Services Manager - Environmental

Wildlands

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