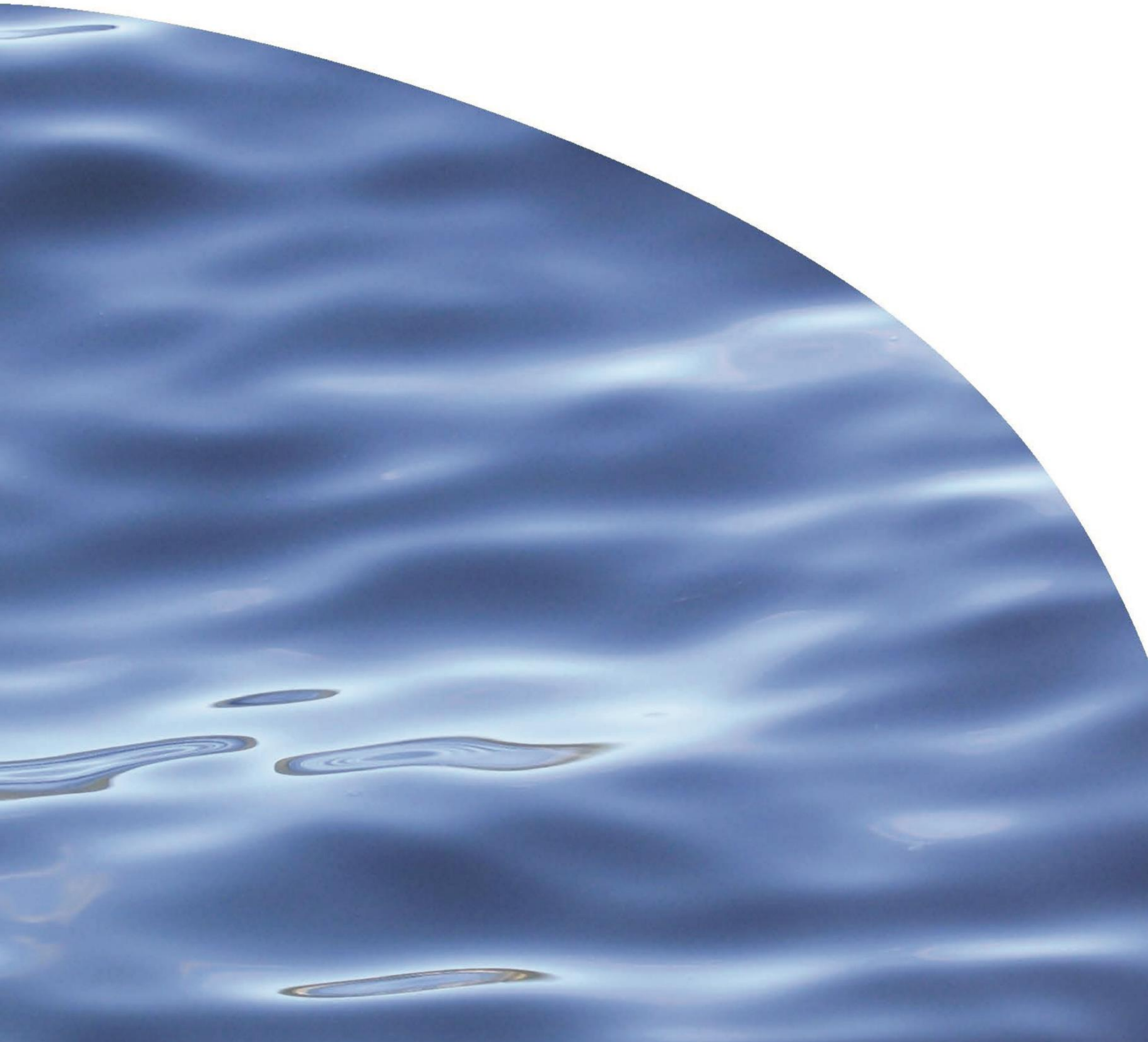
CAWTHRON
The power of science®

REPORT NO. 2882

ADDITIONAL SEABED INFORMATION FOR A FINFISH FARM EFFECTS ASSESSMENT AT TIO POINT, OYSTER BAY, TORY CHANNEL—UPDATED



ADDITIONAL SEABED INFORMATION FOR A FINFISH FARM EFFECTS ASSESSMENT AT TIO POINT, OYSTER BAY, TORY CHANNEL—UPDATED

DANA CLARK, DAVE TAYLOR

Prepared for Ministry for Primary Industries

This report has minor changes from the version issued on 23 September 2016

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Grant Hopkins

APPROVED FOR RELEASE BY:
Chris Cornelisen

ISSUE DATE: 27 September 2016

RECOMMENDED CITATION: Clark D, Taylor D 2016. Additional Seabed Information for a finfish farm effects assessment at Tio Point, Oyster Bay, Tory Channel. Prepared for Ministry of Primary Industries. Cawthron Report No. 2882. 23 p. plus appendices.

EXECUTIVE SUMMARY

The existing owners of the resource consent for marine farm 8409 at Tio Point, Oyster Bay, Tory Channel, wish to assess the feasibility of shifting the consent area into deeper water and farming finfish. This report presents the results of a survey to accurately map the bathymetry of the site, characterise habitats inshore of the proposed farm where farm deposition is likely to accumulate and determine the extent of the novel habitats observed in previous surveys. In addition, depositional modelling was used to determine the intensity and extent of the depositional footprint of the farm and calculate appropriate levels of feed input with regard to acceptable seabed enrichment.

Improved bathymetric mapping showed that the existing and proposed marine farm sites are situated in slightly deeper water than previously reported, particularly over the proposed net pen location. The eastern corner of the proposed site is situated beside a depression that, depending on the hydrodynamic features around the nearby headland, may accumulate deposition from a finfish farm. Monitoring at the nearby depression after three years at full feed discharge would determine if accumulation and excessive enrichment were occurring.

The benthic habitats in the vicinity of the existing and proposed marine farm sites were predominantly sand/mud and shall hash with relatively sparse epibiota (sea stars, hydroids etc.). These habitats are widespread in the Marlborough Sounds.

A number of novel habitats and taxa were recorded in the current survey but most were present at low densities or beyond the boundaries of the proposed site. Burrowing sea cucumbers were not observed in the present survey suggesting this species is unlikely to be widespread in the vicinity of the proposed site. Sabellid tubeworm (*Bispira bispira A*) beds appeared to be restricted to shell hash habitat in vicinity of the proposed farm and may be impacted by farm deposition. Hydroid trees (*Solanderia* sp.) were observed occasionally in the vicinity of the proposed site, however, they appeared to be low in number and more limited in extent than the communities found on the north eastern coast of Tory Channel.

At feed inputs of 1600 t yr^{-1}, deposition is not expected to result in enrichment beyond the level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds (ES 5). The level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions within ca. 500 m.

The majority of the depositional footprint extends to north of the proposed net pens, and away from much of the potentially sensitive inshore reef area and the large tubeworm mound identified in previous surveys.

Habitats inshore of the proposed farm were typical of Tory Channel and included reef communities that may be affected by farm deposition. While reefs in proximity to nearby salmon farms at Te Pangu and Clay Point have not shown farm-related impacts, some indications of enrichment have recently been observed. Due to the proximity of the proposed farm, it is suggested that any future monitoring plan should include the reef communities and the depression to the east of the Tio Point farm to ensure enrichment effects remain minor.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

1. INTRODUCTION

The owners of the resource consent (U990908) for Marine Farm 8409 at Tio Point, Oyster Bay, Tory Channel, wish to assess the feasibility of shifting the consent area into deeper water and farming finfish. Marine Farm 8409 was used as a mussel farm from 2001–2005, but the majority of surface structures were removed in 2008. The Ministry of Primary Industries (MPI) contracted Cawthron to undertake a desktop review of existing information regarding the benthic environment at this potential finfish farm site. Four pieces of information were provided; a preliminary ecological survey (Anderson & Grange 2013), a subsequent site assessment (O'Callaghan et al. 2014) and water temperature and current data from previous work undertaken by NIWA in 2013-2015. This review was provided to MPI in May 2016 (Cawthron Advice Letter No. 1622), and determined that the information contained in the two NIWA reports had most of the components necessary for a resource consent application, however, some key information gaps were identified:

- improved bathymetric mapping to identify areas of likely accumulation of farm deposits
- a better understanding of the extent of the novel habitats observed (particularly burrowing holothurian habitat) and their sensitivity to finfish farm deposition
- inshore habitat survey and characterisation (particularly along the western shoreline)
- an understanding of infaunal community structure within the existing and proposed farm areas (may be able to be assessed in a future baseline survey).

This report presents the results of an additional survey to accurately map the bathymetry of the site, characterise habitats inshore of the proposed farm where farm deposition is likely to accumulate and determine the extent of the novel habitats observed in previous surveys. In addition, depositional modelling was used to determine the intensity and extent of the depositional footprint of the farm and calculate appropriate levels of feed input with regard to acceptable seabed enrichment. An assessment of infaunal community composition at the site would be undertaken during a full baseline benthic survey, if one is commissioned in the future.

2. METHODS

The survey work was undertaken on 24 May 2016, from the Cawthron research vessel *Waihoe*.

2.1. Bathymetry

Bathymetric data were collected to produce a fine-scale bathymetric map of the proposed site. The research vessel was driven systematically across the bay while depth and location data were collected using a Lowrance depth sounder. The depths were tidally-corrected and interpolated using the ArcGIS Spatial Analyst toolbox in ESRI ArcMap (v 10.2.2). A three-dimensional bathymetry map was also created using ESRI ArcScene (v 10.2.2).

2.2. Side-scan sonar

Side-scan sonar was used to characterise seabed composition (e.g. soft sediments vs reef and rocky habitats) in the vicinity of the potential finish site. Side-scan sonar information was collected using a Lowrance StructureScan HD side-scan (455 kHz) fixed to the hull of the research vessel, with a swath of 100 m (50 m either side). A live data-feed was received and logged by Lowrance HDS-12 Gen 2 touch plotter. Side-scan sonar imagery was processed using SonarTRX software to convert the sonar files to geo-referenced images for overlay in ESRI ArcMap (v 10.2.2) and Google Earth Pro.

2.3. Benthic sled video imagery

Video imagery was used to characterise the habitats surrounding the proposed site and determine the extent of novel habitats. Live-feed and enclosed SeaViewer video equipment was mounted to a benthic sled, which was towed behind the research vessel. Ten video sled transects were recorded, traversing the existing and proposed sites and covering the area inshore of the proposed farm where farm deposition is likely to accumulate (Figure 1). Transition areas between habitat types were identified from video footage and cross referenced to time and depth information to determine their location within the site. Currents, changes in water depth and the amount of cable out at a given time all affect the layback of the video sled, therefore, these transition zones between habitats should be interpreted with some degree of caution.

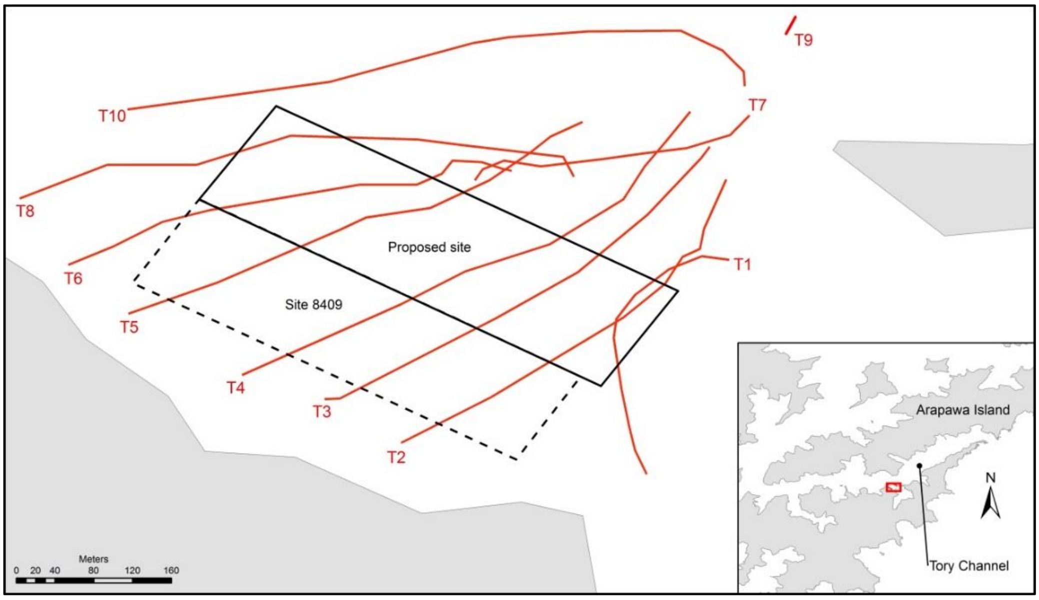


Figure 1. Location of video sled transects undertaken during additional survey work at marine farm site 8409 and a proposed new site at Tio Point, Oyster Bay, Tory Channel. Transect nine is short because the video sled flipped in high currents.

2.4. Depositional modelling and predicted Enrichment Stage (ES)

Depositional modelling was used to determine the intensity and spatial extent of the depositional footprint of the proposed farm and appropriate levels of feed input with regard to acceptable seabed enrichment. Acceptable seabed enrichment effects were assessed using Enrichment Stage (ES), which is a derivative of multiple physico-chemical and biological variables. This approach is consistent with the Best Management Practice guidelines for salmon farms in the Marlborough Sounds (BMP, Keeley et al*.* 2015b).

2.4.1. Calculation of Enrichment Stage scores

Calculation of ES scores is described in detail by Keeley et al. (2012a, 2012b). Scores are first calculated for each of: total organic matter, redox potential, total free sulphides and various macrofauna indices (abundance, number of taxa, Margalef's richness, Shannon Wiener diversity, Pielou's evenness, 'Benthic Quality Index' BQI and 'AZTI Marine Biotic Index' AMBI; see Appendix 1 for background information). Combinations of these values are 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 and averaging are used to combine these three scores into a single overall ES score (Figure 2). The group weightings used in the present study were: 0.1 for the organic loading score, 0.2 for the sediment chemistry score and 0.7 for the macrofauna score. These weightings are based on best professional judgement, taking into account the relative strengths of their association with expertly-assessed ES.

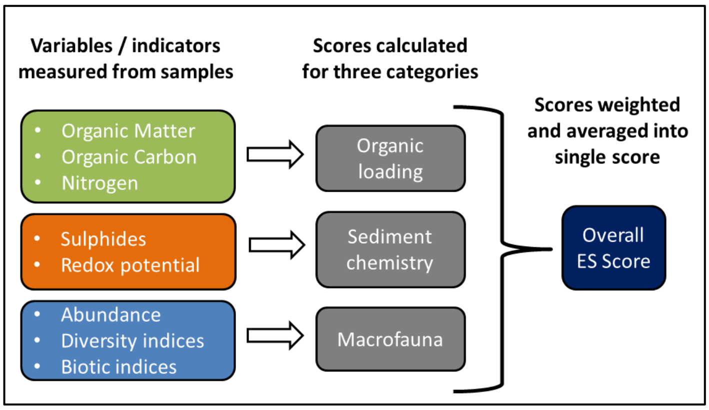


Figure 2. Diagram showing the variables measured within categories that are used to calculate the overall Enrichment Stage (ES) score.

2.4.2. Depositional modelling

Deposition of farm waste is the primary driver of seabed impacts from finfish farms, and particle tracking models have become an accepted and useful tool to predict and manage their extent (Henderson et al. 2001). DEPOMOD (version 2.2), a model specifically developed to predict the organic deposition from salmon farms (Cromey et al. 2002), was used to predict the intensity and extent of the depositional footprint for a series of possible feed loadings at the Tio Point site.

To predict the effects of the modelled depositional footprints in terms of ES, thresholds of depositional flux were used (Keeley et al. 2013a). At dispersive sites, like Tio Piont, approximately 13 kg of solids m^{-2} yr^{-1} have been shown to produce a state of very high enrichment with an overall ES of 5 (Keeley et al. 2013a), which is currently considered to be the maximum level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds (Keeley et al. 2015b). Therefore, in line with the recommendations of the BMP, we used 13 kg of solids m^{-2} yr^{-1} as a maximum allowable threshold of deposition. Feed inputs used in DEPOMOD were reduced until the maximum depositional flux to the seabed was less than or equal this threshold (modelled feed inputs of 4000, 2000, 1600, 1200 and 1000 kg of solids m^{-2} yr^{-1}).

The models were run using one row of four cages aligned at 300°, as recommended by O'Callaghan et al. (2014). Bathymetry data used in the model is described in Section 3.1. The model used actual current data collected with an Acoustic Doppler Current Profiler (ADCP, RD Instruments) by O'Callaghan et al. (2014). The ADCP was deployed from 1 August–13 September 2013, close to the farm in approximately 36 m water depth (41°14.827'S, 174°14.159'E). Models were run using no-resuspension, a scenario where there is one-way flux to the sediment, and can therefore be treated as a worst-case scenario with regard to seabed impacts. A summary of the detailed model input parameters and settings is provided in Appendix 2[1].

3. RESULTS

3.1. Bathymetry map

The existing marine farm site is situated in water depths of approximately 9-31 m (Figure 3 and Figure 4). The proposed new site is deeper, with the inshore boundary in depths of 18-31 m and the offshore boundary in depths of 26-44 m. The eastern corner of the proposed site is situated in a depression, approximately 31 m at its deepest point.

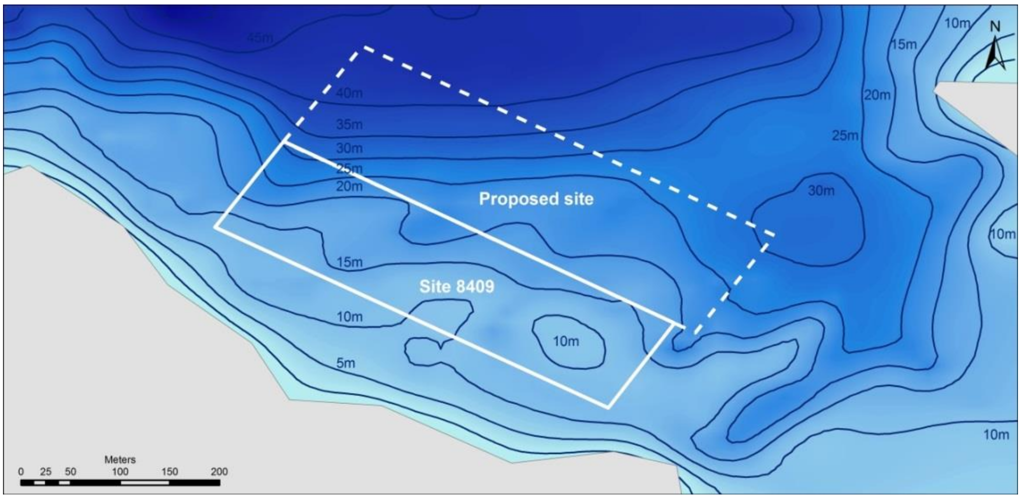


Figure 3. Two-dimensional bathymetry map for the area surrounding marine farm site 8409 and a proposed new site at Tio Point, Oyster Bay, Tory Channel. Depths are in metres relative to mean sea level, as shown on the contour lines.

[1] Input parameters for DEPOMOD differ slightly from those used in a recent NIWA benthic report (Brown et al. 2016). A comparison of model parameters and subsequent outputs found that, due to the faster particle sinking rates used, the NIWA parameters predicted a slightly higher deposition rate in the immediate vicinity of the farm pens, but overall the shape and magnitude of the depositional footprints were similar (Jeffrey Ren, NIWA, pers. com.).

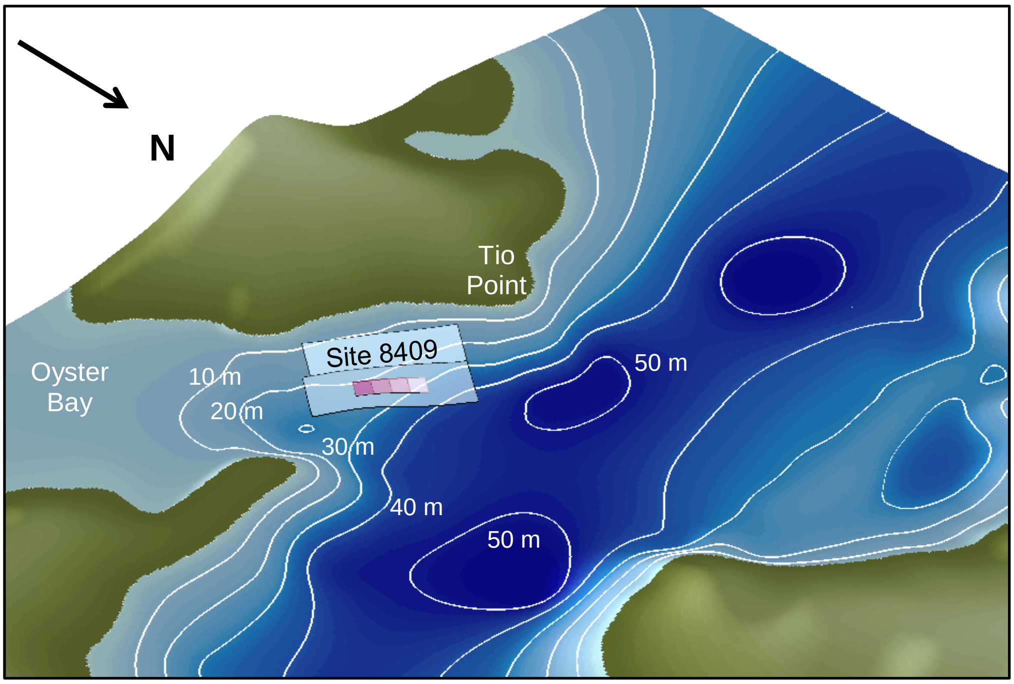


Figure 4. Three-dimensional bathymetry map for the area surrounding marine farm site 8409 and a proposed new site at Tio Point, Oyster Bay, Tory Channel. Depths are in meters relative to mean sea level, as shown on the contour lines.

3.2. Side-scan sonar

Side-scan sonar imaging identified areas of reef and rocky habitat inshore of the existing site and extending from both headlands (Figures 5–9). Isolated 'rocks' were also observed offshore and may be associated with tubeworm habitat, as identified in previous reports (O'Callaghan et al. 2014).

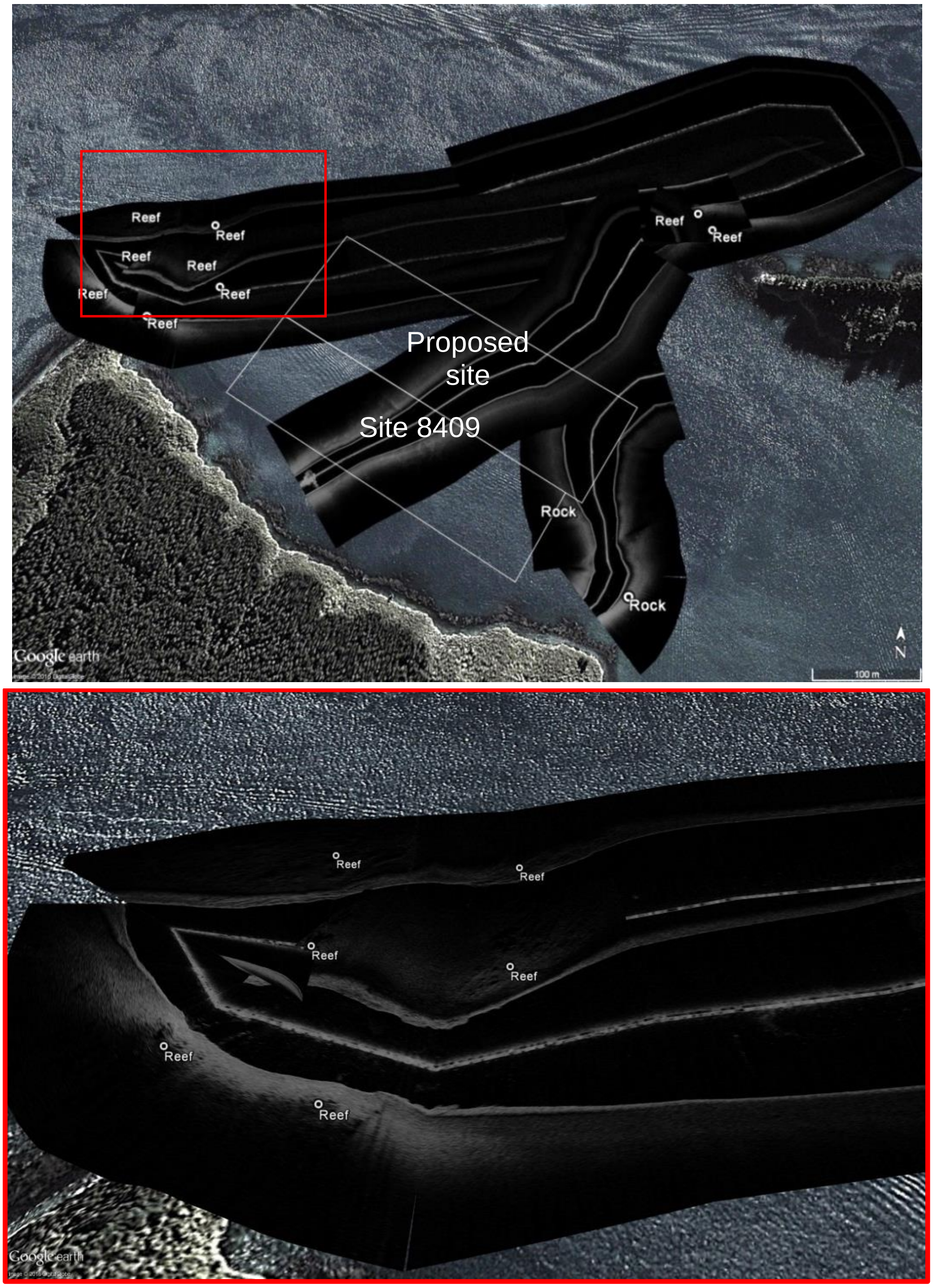


Figure 5. Side-scan sonar imaging for the area surrounding marine farm site 8409 and a proposed new site at Tio Point, Oyster Bay, Tory Channel. The bottom panel shows a closer view of the area marked by the red box in the top panel.

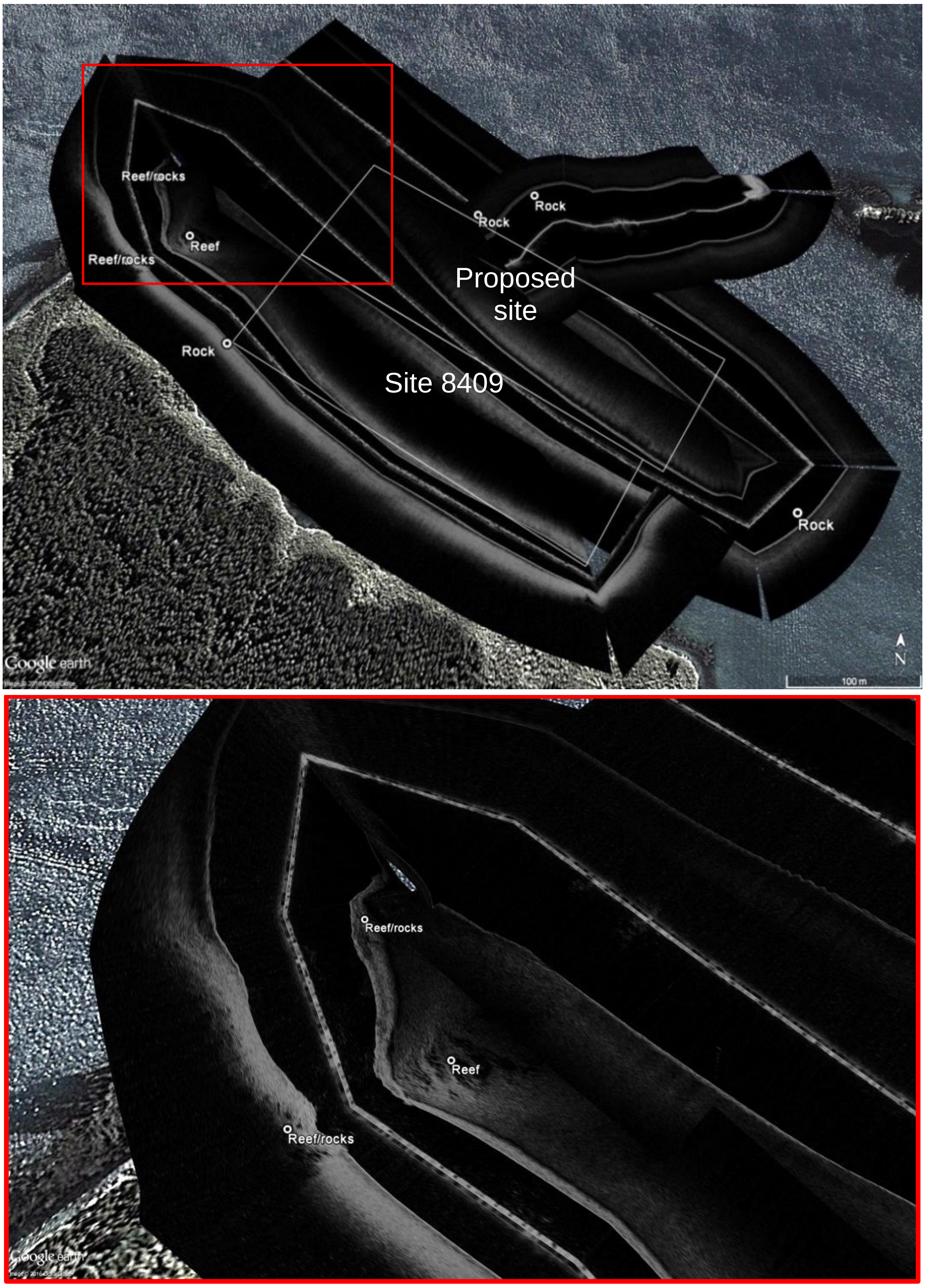


Figure 6. Side-scan sonar imaging for the area surrounding marine farm site 8409 and a proposed new site at Tio Point, Oyster Bay, Tory Channel. The bottom panel shows a closer view of the area marked by the red box in the top panel.

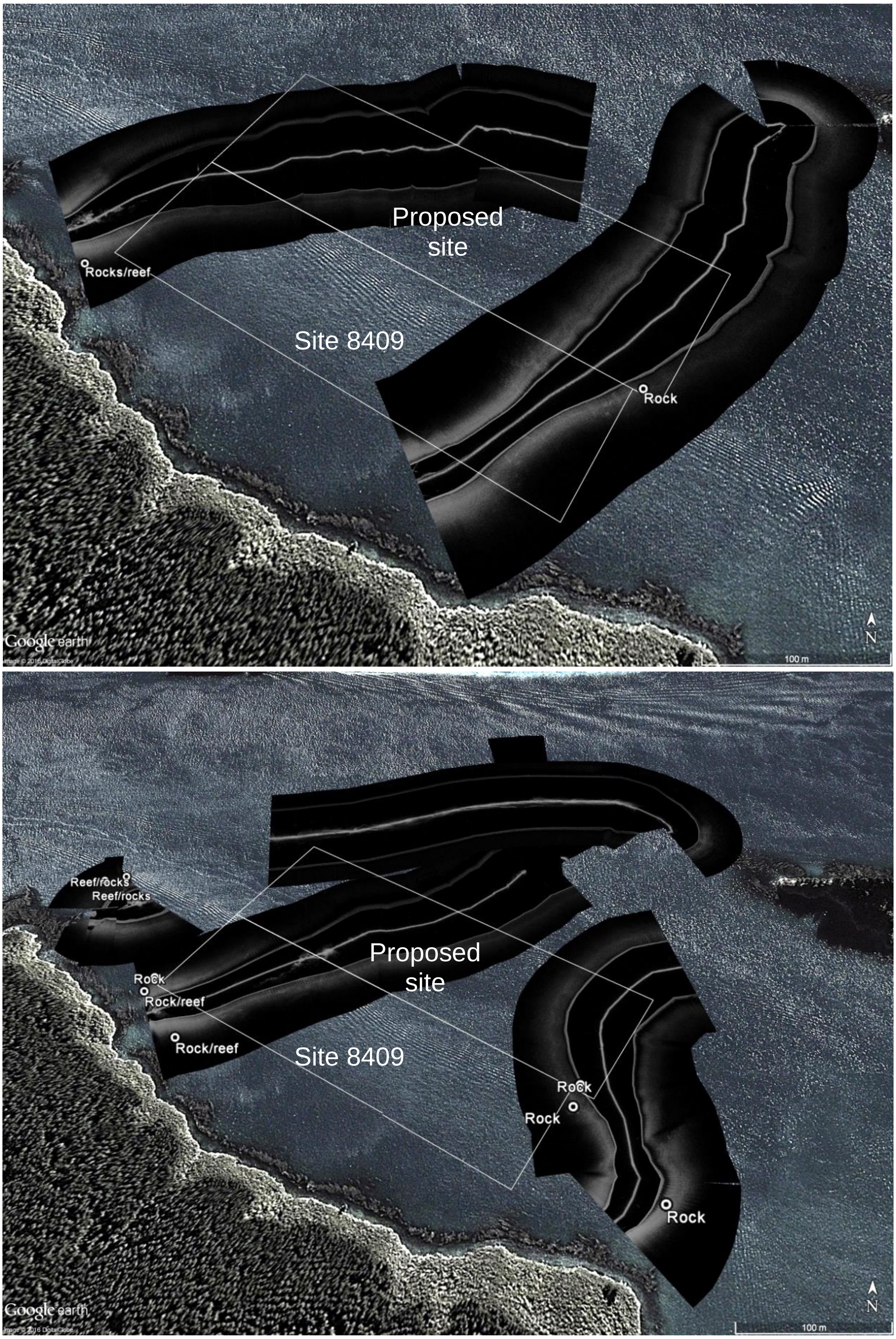
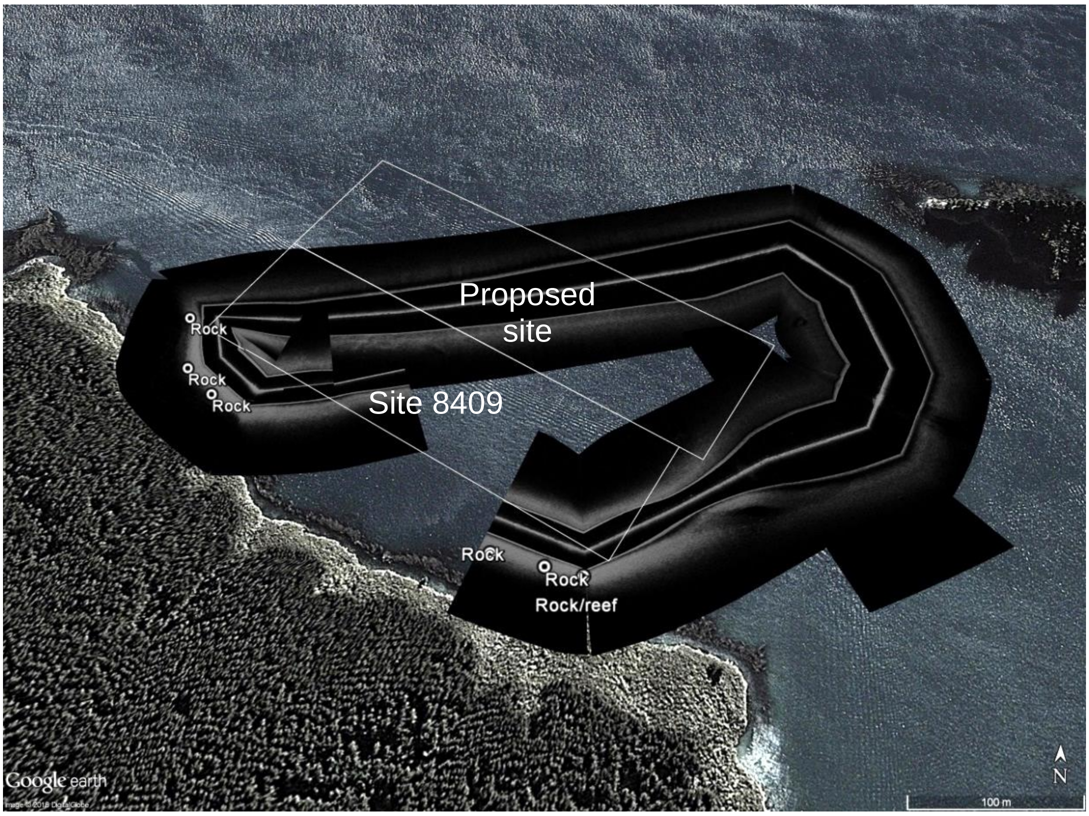


Figure 7. Side-scan sonar imaging for the area surrounding marine farm site 8409 and a proposed new site at Tio Point, Oyster Bay, Tory Channel.



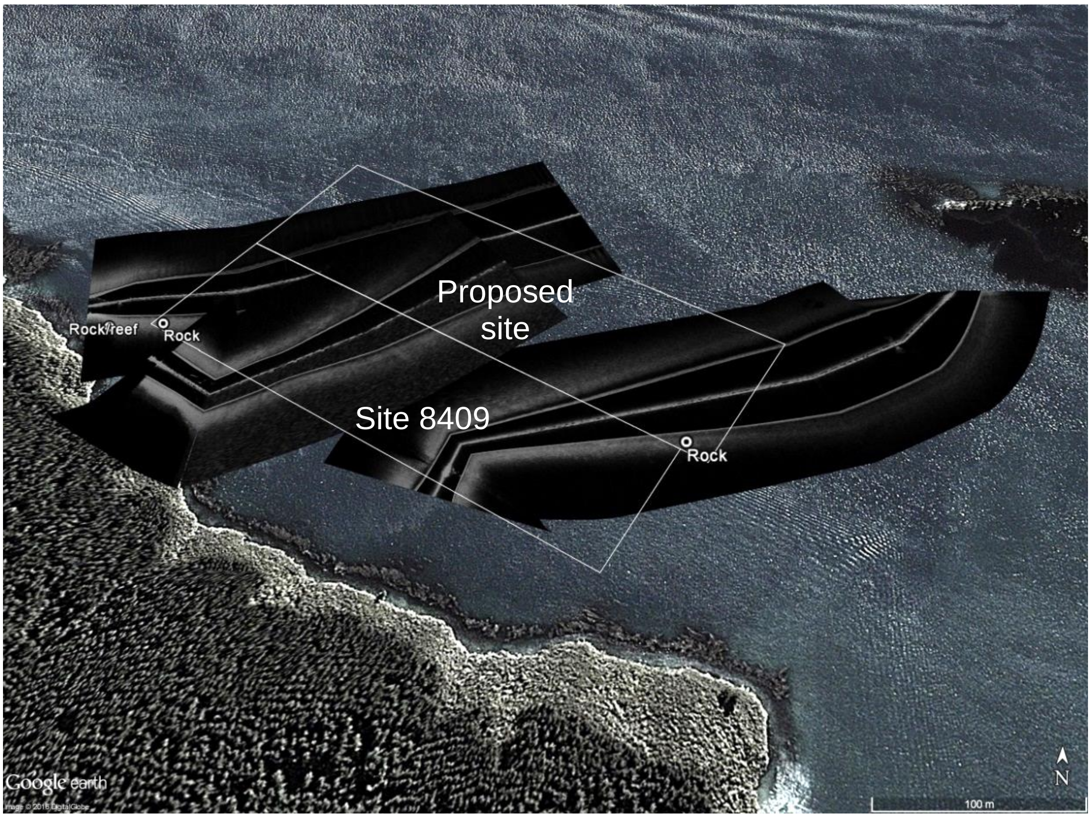


Figure 8. Side-scan sonar imaging for the area surrounding marine farm site 8409 and a proposed new site at Tio Point, Oyster Bay, Tory Channel.

3.3. Habitat map

The benthic habitat beneath the existing and proposed sites was primarily sand/mud and shell hash (Figure 9). The sand/mud habitat extended from the reef edge, inshore of the farm, and transitioned into shell hash habitat in deeper depths where presumably stronger currents occurred.

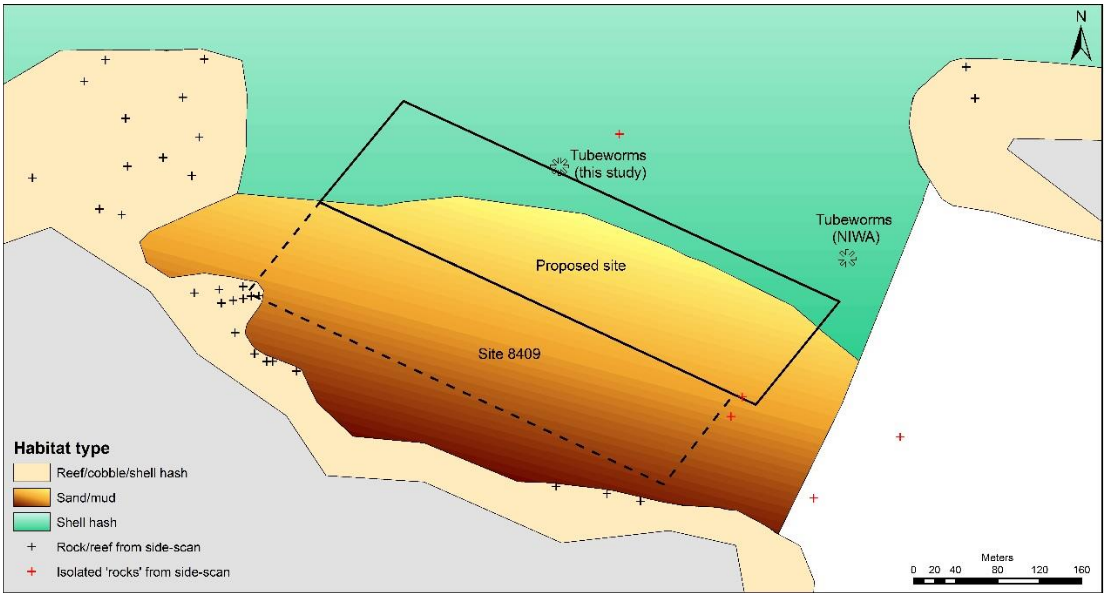


Figure 9. Habitat map for the area surrounding marine farm site 8409 and a proposed new site at Tio Point, Oyster Bay, Tory Channel. The shading in the sand/mud area represents the disappearance of the microphytobenthos (MPB) in deeper areas. NB: Locations of transition zones between habitats were produced from video laybacks and are estimates only.

In shallower areas of the sand/mud habitat, the seafloor was covered with patchily distributed microphytobenthos (MPB; Figure 10). MPB are unicellular algae, which make an important contribution to primary production. Some areas of the sand/mud habitat were relatively bare, with few biota other than brittle stars (*Ophiopsammus maculatus*) and cushion stars (*Pateriella regularis*). In other areas, red algae (various species including *Rhodymenia* sp. and *c.f. Gigartina atropurpurea*) were sparse to moderately abundant and sea lettuce (*Ulva* sp.), *Undaria pinnatifida, Carpophyllum flexuosum*, bladder kelp (*Macrocystis pyrifera*), *Carpomitra costata* and dead man's fingers (*Codium fragile*) were occasionally observed. Other biota recorded in the sand/mud habitat included sea cucumbers (*Australostichopus mollis*), kina (*Evechinus chloroticus),* eleven-armed sea stars (*Coscinasterias calamaria*), five armed sea stars (*Sclerasterias mollis*), large finger sponges, biscuit stars (*Pentagonaster pulchellus*), hermit crabs (*Pagurus* sp.), purple fan worms (*Sabella* sp.), sea tulips (*Pyura c.f. pachydermatina*) and the anemone *c.f. Epiactis thompsoni*. Biogenic clumps were occasionally observed and these commonly comprised encrusting and erect sponges, colonial and solitary ascidians, hydroids, moss bryozoans (Catenicellidae), bryozoans (including *Celleporaria agglutinans*) and red algae. Some of the biogenic clumps were formed around horse mussels (*Atrina zelandica*), with seven horse mussels observed overall in the sand/mud habitat. Five tree hydroids (*c.f. Solanderia* sp.), two live scallops (*Pecten novaezelandiae)* and a duck's bill limpet (*Scutus breviculus*) were also recorded. Fish observed included spotties (*Notolabrus celidotus*), blue cod (*Parapercis colias*), sand flounder (*Rhombosolea plebeian*) and opal fish (*Hemerocoetes monopterygius*).

The shell hash habitat was characterised by large amounts of dead shell and occasional epifaunal species (Figure 11). Biota was comparable to the sand/mud habitat, with less red algae and no brown or green algae present (other than drift *Ulva* sp.). A burrowing anemone (*Cerianthus* sp.) was recorded and as well as three tree hydroids (*c.f. Solanderia* sp.). Biogenic clumps, similar to those found in the sand/mud habitat, were occasionally observed. Some of these were formed around horse mussels, with ten horse mussels observed overall in the shell hash habitat. Fish observed in this habitat included blue cod (*P. colias*) and spotties (*N. celidotus*).

Unlike the sand/mud habitat, the shell hash habitat contained *Bispira bispira A*, the sabellid polychaete tubeworm observed during a previous survey (O'Callaghan et al. 2014). A couple of large patches were observed at the end of video transect six, and a few individuals were observed along four other transects (Figure 9 and Figure 11). These tubeworm patches were associated with brittle stars, red algae, biscuit stars, horse mussels, sea cucumbers, cushion stars and solitary ascidians.

Reef and cobble, interspersed with sand or shell hash near the edge, was present at the two headlands and along the coastline inshore of the existing site. The reef/cobble area had higher biodiversity than other habitats in the bay, with biota typical of similar habitats in the Marlborough Sounds (Figure 12). Taxa present included bladder kelp, red algae (various species including *Rhodymenia* sp.), sea lettuce, colonial and solitary ascidians, bryozoans (including *C. agglutinans*), encrusting and erect sponges, coralline paint, hydroids (including *Solanderia* sp.), brittle stars, cushion stars, eleven-armed sea stars, moss bryozoans, sea cucumbers, hermit crabs, kina and a burrowing anemone. Fish were more abundant in this habitat than elsewhere in the bay and included butterfly perch (*Caesioperca lepidoptera*), tarakihi (*Nemadactylus macropterus*), sea perch (*Helicolenus percoides*), blue cod (*P. colias*) and scarlet wrasse (*Pseudolabrus miles*).

O'Callaghan et al. (2014) noted the presence of a burrowing holothurian sea cucumber (*c.f. Pentadactyla longidentis*) in tubeworm habitat and the surrounding soft sediments. This species was not observed in any of the video transects undertaken in the present survey.

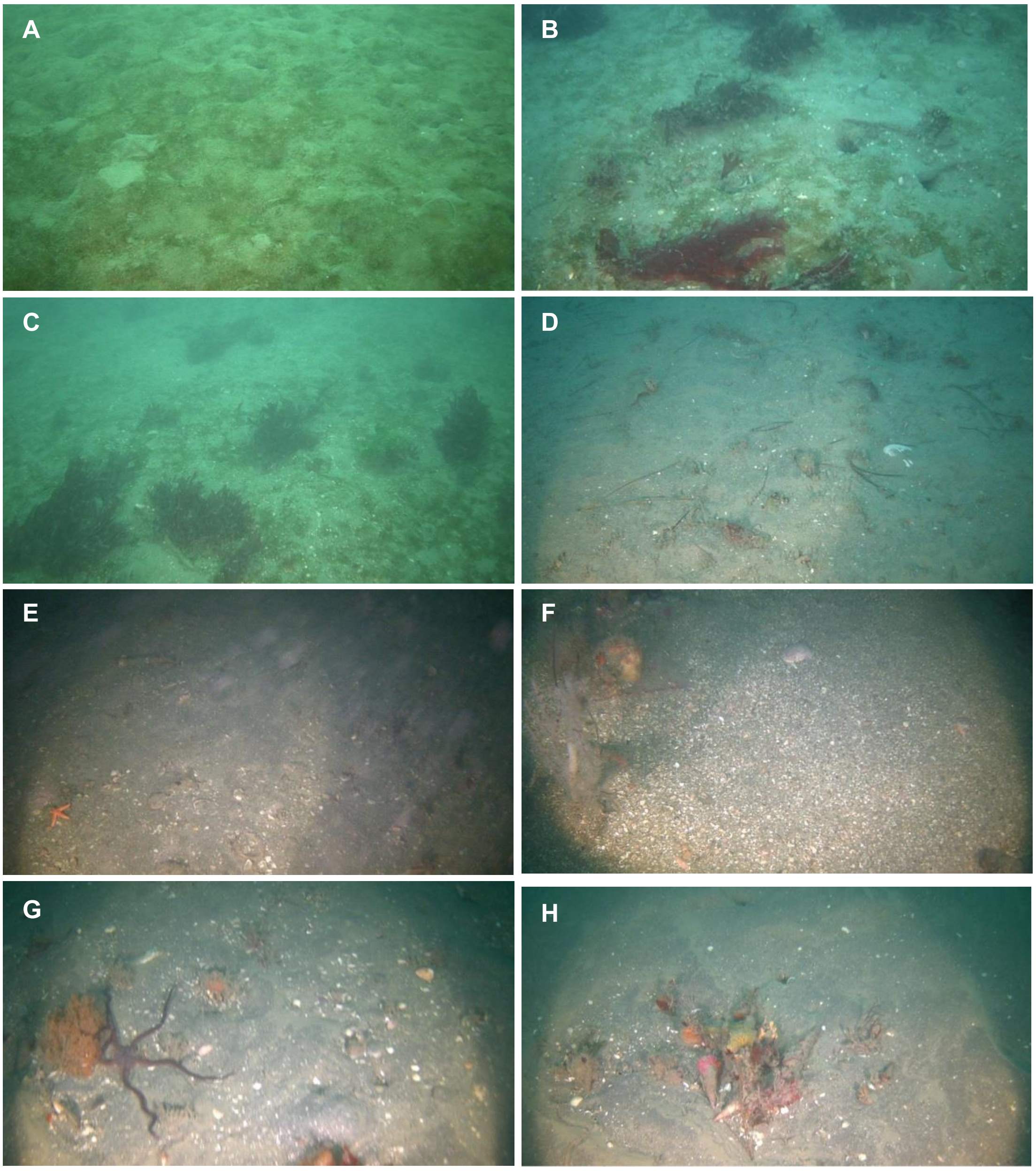


Figure 10. Representative images of the sand/mud habitat (captured from video footage). A: microphytobenthos (MPB) and cushion stars (T3), B: MPB, red algae and cushion stars (T4), C: MPB and red algae (T2), D: sand (T5), E: sand with a small sea star (T5), F: sand with a tree hydroid (*Solanderia* sp.) (T8), G: brittle star and moss bryozoan (T2), H: hermit crabs, solitary ascidians and hydroids (T2).

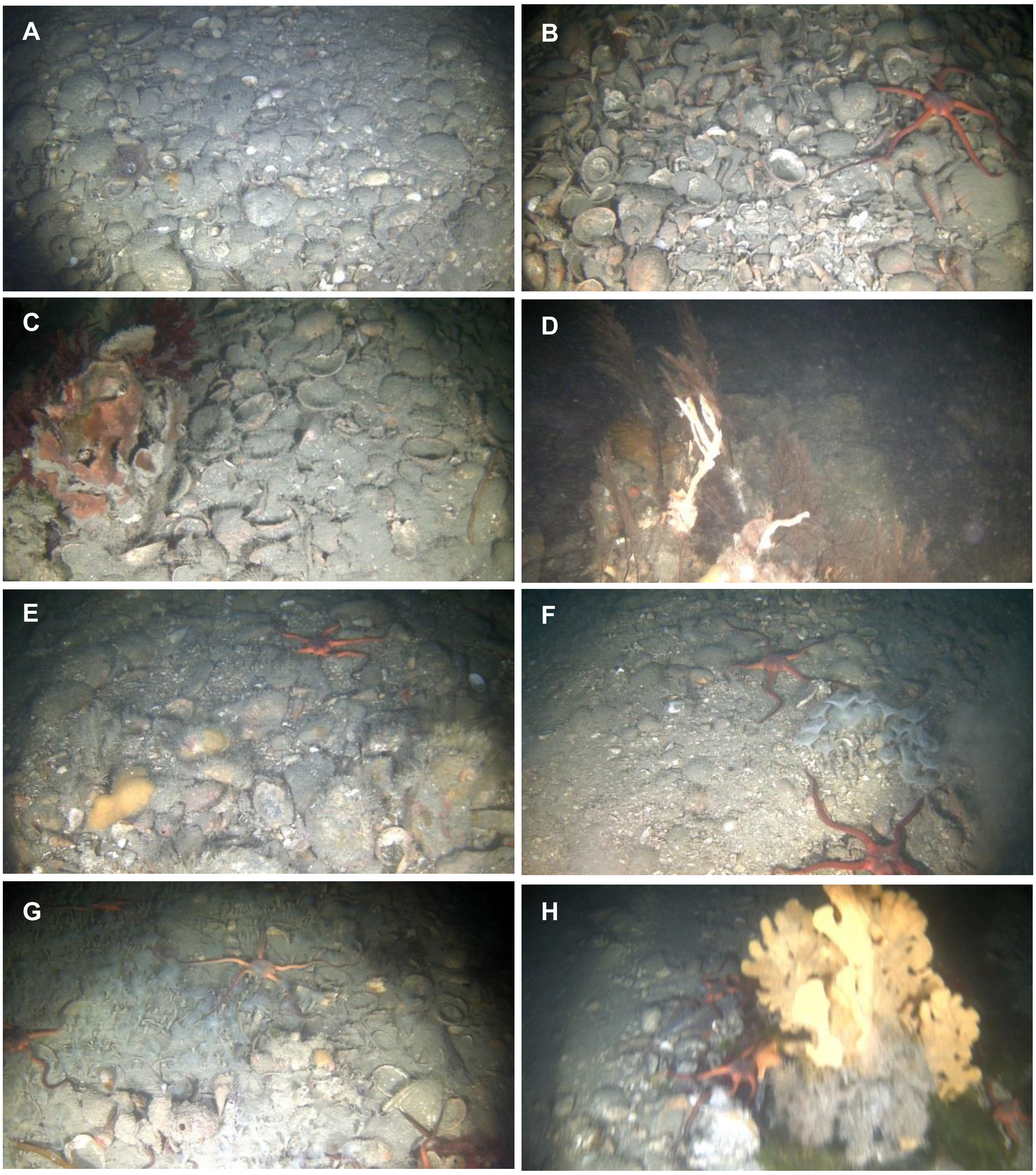


Figure 11. Representative images of the shell hash habitat (captured from video footage). A: purple fan worm and feather hydroid (T8), B: brittle star (T2), C: biogenic clump with bryozoan (*Celleporaria agglutinans*) and red algae (T2), D: tree hydroids (*Solanderia* sp.) and colonial ascidians (T9), E: colonial ascidians, brittle star, solitary ascidian, hydroids and horse mussel (T7), F: brittle stars and tubeworms (T4), G: large patch of tubeworms with brittle stars and solitary ascidians (T6), H: large sponge, brittle stars, cushion stars (T7).

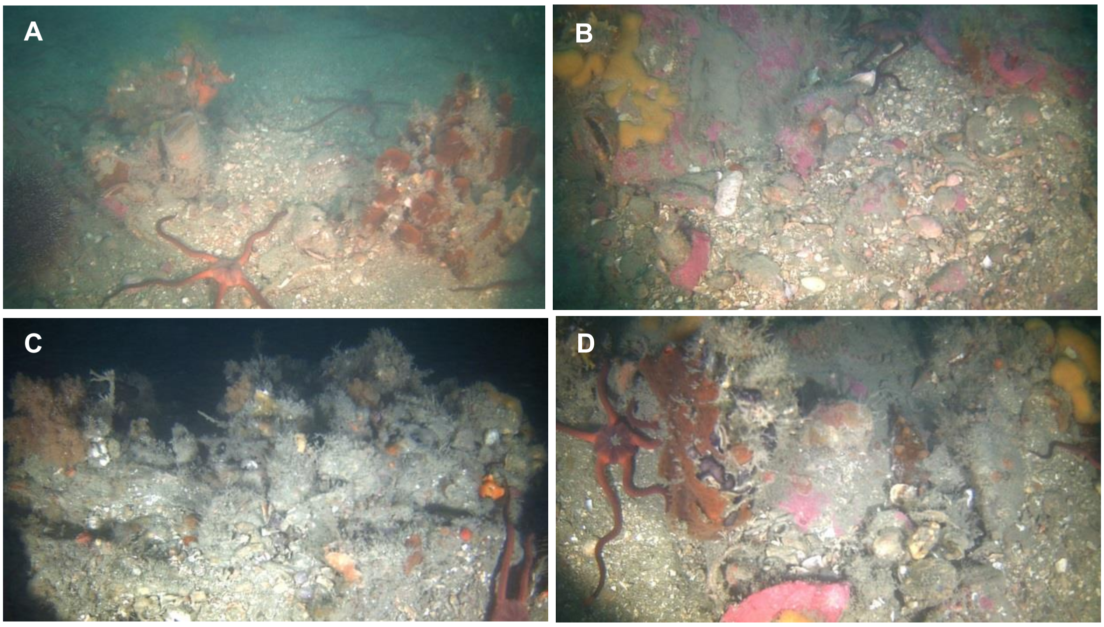


Figure 12. Representative images of the reef/cobble/shall hash habitat (captured from video footage). A: Burrowing anemone, bryozoan, kina, brittle star (T8); B: colonial ascidian, coralline paint, hydroids (T8), C: moss bryozoan, hydroids, brittle star (T8), D: solitary ascidians, brittle star, bryozoan, colonial ascidian, hydroids, sea cucumber (T8).

3.4. Depositional modelling and predicted Enrichment Stage (ES)

At feed inputs of 1600 t yr^{-1}, predicted farm deposition reached 13 kg of solids m^{-2} yr^{-1}, a threshold of deposition which is expected to produce ES 5 conditions and is the upper level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds (Keeley et al. 2013a; Keeley et al. 2015b). Deposition was primarily concentrated beneath the farm and was predicted to move away from the farm in a northwest direction toward the main channel (Figure 13 and Figure 14). The overall area directly affected by deposition was estimated at *ca.* 62 ha, with most of this area (*ca.* 57 ha) exposed to ≤ 1 kg m^{-2} yr^{-1}, which is equivalent to near background conditions (< ES 3; Keeley et al. 2013a; Keeley et al. 2013b). Only *ca*. 4.5 ha was exposed to deposition between 1 and 13 kg m^{-2} yr^{-1}, equivalent to ES 3-5, with most of that area unlikely to reach a state of very high enrichment (ES 5).

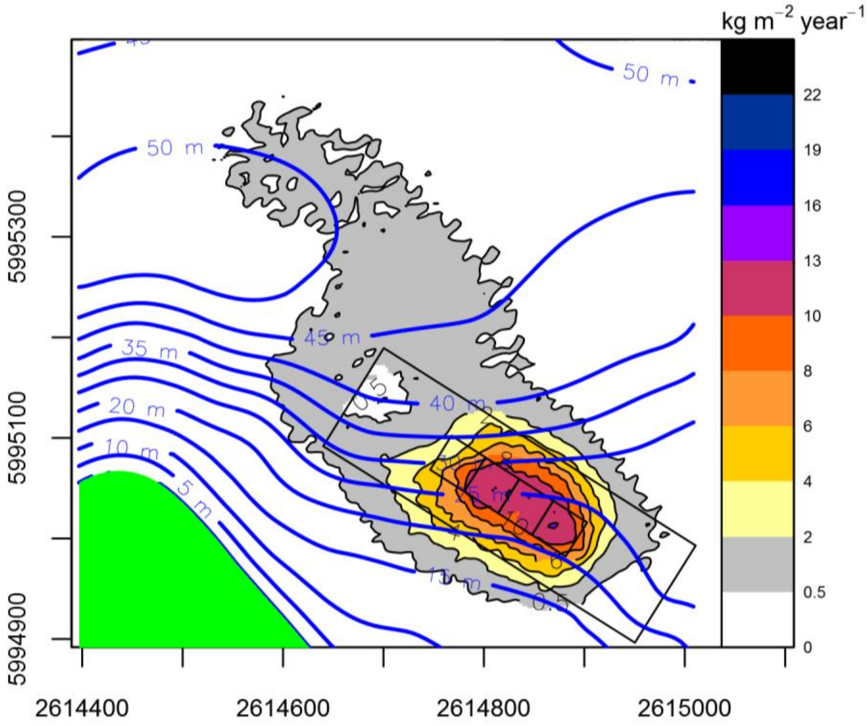


Figure 13. Predicted depositional footprint from the proposed finfish farm at Tio Point, Oyster Bay, Tory Channel. Deposition was estimated using DEPOMOD (no resuspension) with feed inputs set at 1600 t yr^{-1} and deposition is in kg of solids m^{-2} yr^{-1}. Depth contours are shown in blue and land is shown in green.

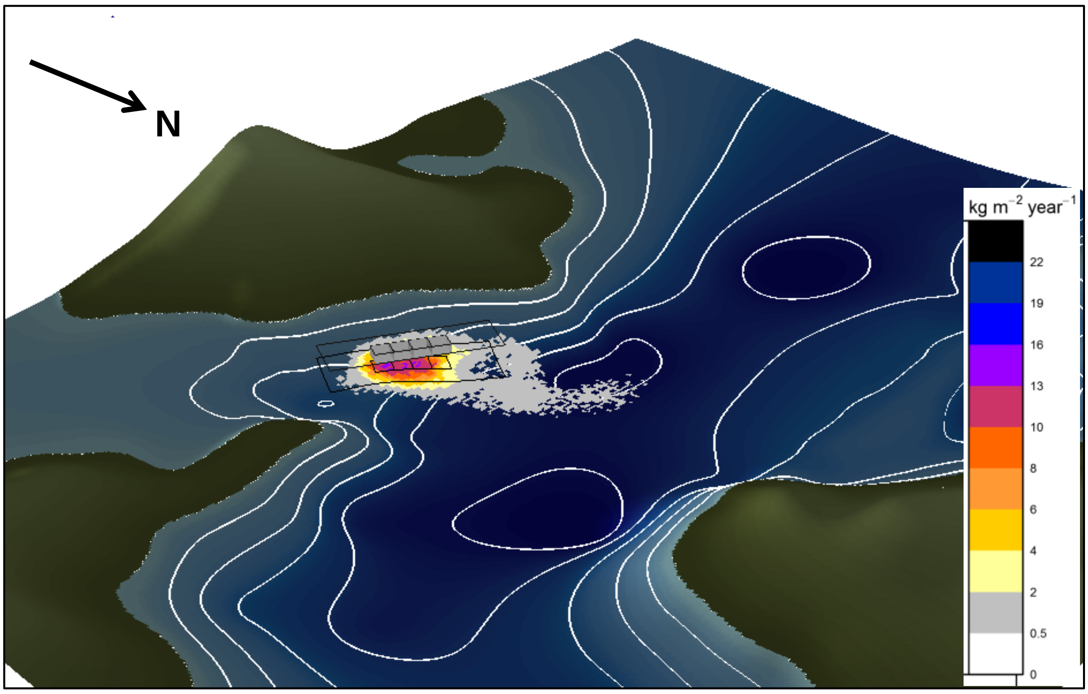


Figure 14. Three-dimensional representation of the predicted depositional footprint at the proposed finfish farm at Tio Point, Oyster Bay, Tory Channel. Deposition was estimated using DEPOMOD (no resuspension) with feed inputs set at 1600 t yr^{-1}. Deposition is in kg of solids m^{-2} yr^{-1}. Depth contours are shown in white.

The predicted depositional footprint of the proposed farm was overlaid onto the habitat map to enable assessment of the potential effects of farm deposition on ecological features at the site (Figure 15). Predicted deposition is concentrated over sand/mud and shell hash habitats and avoids potentially sensitive reef habitats inshore of the proposed farm and the large tubeworm patch identified by O'Callaghan et al. (2014).

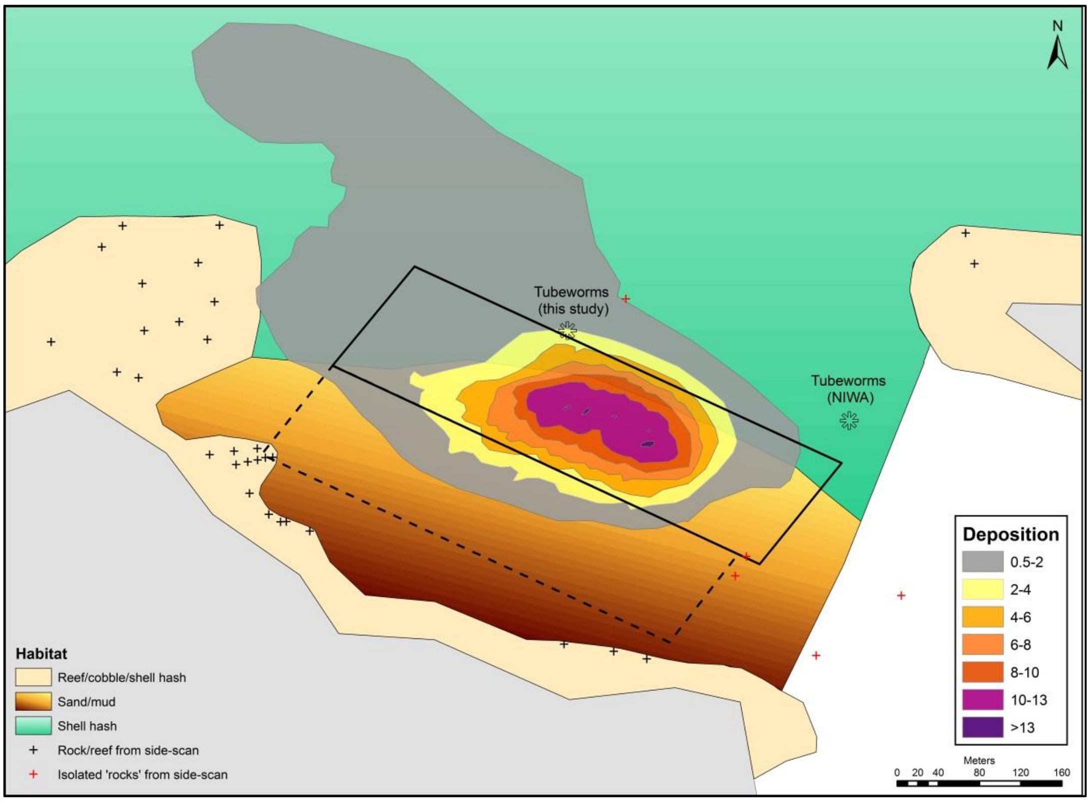


Figure 15. Predicted depositional footprint overlaid onto the habitat map generated for the proposed finfish farm at Tio Point, Oyster Bay, Tory Channel. Deposition was estimated using DEPOMOD (no resuspension) with feed inputs set at 1600 t yr^{-1} and deposition is in kg of solids m^{-2} yr^{-1}. NB: Locations of transition zones between habitats were produced from video laybacks and are estimates only.

4. DISCUSSION

4.1. Bathymetry

The detailed bathymetry map established that the existing and proposed marine farm sites are situated in slightly deeper water than previously reported. Anderson and Grange (2013) estimated the existing site to be in water depths of approximately 8-21 m and the proposed site in depths of 15–43 m, compared with 9–31 m and 18-44 m estimated with our updated fine-scale bathymetric data. In addition, the eastern corner of the proposed site is situated beside a depression, approximately 31 m deep, which may have potential to accumulate deposition from a finfish farm. This secondary deposition (i.e. re-suspension and re-deposition of fish farm material) is not well described by DEPOMOD and may lead to localised patches of enriched seabed. To determine this with more confidence, more detailed hydrodynamic modelling would be required. Alternatively, this potential depositional zone could be targeted during monitoring if the site is developed into a finfish site.

4.2. Benthic habitats

The benthic habitats in the vicinity of the existing and proposed marine farm sites were predominantly sand/mud and shell hash with relatively sparse epibiota. These habitats are widespread in the Marlborough Sounds. MacDiarmid et al. (2013) note that shell hash habitats (‘bivalve beds’) provide settlement substrate for organisms such as sponges and bryozoans and shelter for mobile invertebrates and fishes, creating biogenic structure in what may be an otherwise ‘featureless’ habitat.

Epibiota were patchy, with species such as brittle stars and cushion stars common throughout the area, but other species such as ascidians, hydroids, sponges and bryozoans concentrated in clumps. Davidson et al. (2010) notes the occurrence of biogenic clumps in various locations in the Marlborough Sounds, including high density areas in six soft bottom locations in Tory Channel. The report describes such structures as clumps formed by combinations of species often living in association, where no one species of biogenic habitat former dominates. Biogenic patches of biodiversity are important in attracting and supporting the biodiversity of the area (Davidson et al. 2010), but can be transitory in nature, breaking down and re-colonising over time. The biogenic clumps present around the existing and proposed marine farm sites at Tio Point do not appear to be as abundant as those identified by Davidson et al. (2010) elsewhere in Tory Channel.

The benthic habitats in the vicinity of the proposed site contained eleven taxa or habitats, which have been identified as having particular ecological or scientific importance in the Marlborough Sounds (Department of Conservation 1995; Davidson et al. 2011): blue cod (*Parapercis colias*), horse mussels (*Atrina zelandica*), scallops (*Pecten novaezelandiae*), burrowing anemones (*Cerianthus* sp.), Separation Point 'coral' bryozoan (*Celleporaria agglutinans*), sponge communities, macroalgal beds, tubeworm beds, hydroid trees (*Solanderia* sp.), reef and bladder kelp (*Macrocystis pyrifera*). Most of these taxa and habitats present were in relatively low densities (blue cod, horse mussels, scallops, burrowing anemones, sponge communities, macroalgal beds) or beyond (~60-130 m) the boundaries of the proposed marine farm site (reef, bladder kelp).

The *Bispira bispira A* sabellid tubeworm beds, covered an area > 10% in a distinct zone. Within the Marlborough Sounds, this species has been recorded from Bobs Bay, in Picton Harbour, the northern shore of Waikawa Bay and as an individual from Blow Hole Point, in Pelorus Sound (Davidson et al*.* 2010; Davidson et al*.* 2011). *Bispira bispira A* is also found in Wellington Harbour, Whangarei Harbour, Mount Maunganui, Houhora Harbour in Northland, the Coromandel and Leigh (Davidson et al*.* 2010: Geoff Read, NIWA, pers. comm.). In addition to the 12 x 15 m tubeworm mound identified by O'Callaghan et al. (2014), the present survey recorded two smaller tubeworm beds and scattered individuals elsewhere in the shell hash habitat, suggesting *Bispira bispira A* may be elsewhere in the vicinity of the proposed farm.

Solanderia hydroid trees were also present at the site and at least ten individuals were observed in the present survey. Large hydroid trees can be important three-dimensional biogenic structures, providing habitat for a range of species. The north eastern coast of Tory Channel has a dense hydroid tree dominated benthic community, which is found nowhere else in Marlborough (Davidson et al*.* 2011). However, the hydroid trees around Tio Point appeared to be sparse and more limited in extent than those observed in the north eastern parts of Tory Channel.

Reef and cobble habitat communities observed inshore of the proposed site were typical of those observed elsewhere in Tory Channel with brown algal communities and a range of reef biota (*e.g.* sponges, ascidians, kina, bryozoans, hydroids, sea stars, sea cucumbers and fishes).

The burrowing sea cucumber (*c.f. Pentadactyla longidentis*) recorded by O'Callaghan et al. (2014) was not observed in the present survey, therefore, this species is unlikely to be widespread in the vicinity of the proposed site. *P. longidentis* is common in muddy habitats within the Marlborough Sounds (Davidson et al*.* 2011), but its tolerance of salmon farm deposition is unknown.

4.3. Depositional modelling

The depositional modelling (DEPOMOD) outputs rely on bathymetric data to make their predictions, therefore, we re-ran the DEPOMOD with the new bathymetric data to ensure that the intensity of the predicted depositional footprints were in line with thresholds for deposition recommended in the BMP (Keeley et al*.* 2015b). In contrast to the outputs from O'Callaghan et al. (2014), which predicted the main area of deposition to be between the farm and the shoreline, the updated DEPOMOD outputs predicted deposition to be primarily concentrated beneath the farm, moving away in a north-west direction toward the main channel. The differences are attributed to the different bathymetry settings used in the earlier report. Recent model runs using the updated Cawthron bathymetry have replicated the DEPOMOD outputs shown here (Jeffrey Ren, NIWA, pers. comm.).

Directly beneath the farm cages (< 1 ha), deposition will reach a level where ES 5 impacts may start to occur; i.e. the maximum level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds (Keeley et al. 2015b). Sediments may become highly enriched, the infaunal community diversity will be significantly reduced, a high abundance of opportunistic taxa (i.e. capitellid polychaete worms and nematodes) are expected, bacterial mats (*Beggiatoa*) are usually evident and there may be hydrogen sulphide out-gassing on disturbance (Keeley et al. 2013b).

It is anticipated that a further ca. 4.5 ha of seabed will become moderately enriched (i.e. ES 3 score or more), resulting in major sediment changes, a notable increase in the abundance of benthic infauna, reduced richness and diversity and the dominance of opportunistic taxa (Keeley et al. 2013b). However, the level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions (i.e. ES score < 3) within ca. 500 m.

While the depositional footprint is likely to encompass the occasional notable ecological feature (e.g. biogenic clump, hydroid tree, tubeworm patch), the majority of the depositional footprint extends to north of the proposed net pens, and away from much of the potentially sensitive inshore reef area and the large tubeworm mound identified by O'Callaghan et al. (2014). The deeper depression to the east of the site may be an area where farm deposits could accumulate. Site-specific monitoring within the nearby depression, for example after three years of farming at full feed discharge, would determine if this accumulation and excessive enrichment was occurring.

Reef and cobble habitat was observed inshore of the site at distances of approximately 60 to 130 m from the proposed marine farm. Rocky reef communities in the vicinity (within 80–270 m) of nearby salmon farms at Te Pangu and Clay Point have not been negatively impacted by the farms. However, the closest monitored site (80 m distance) has recently shown some possible signs of mild enrichment, including algal films, darkened sediment and abundant sea lettuce (*Ulva* sp.; Dunmore 2016). While the majority of deposition from the proposed farm is predicted to move away from this reef area, due to the close proximity of the farm it will be important to monitor the reef communities at Tio Point to check for signs of enrichment.

5. CONCLUSIONS

- Improved bathymetric mapping showed that the existing and proposed marine farm sites are situated in slightly deeper water than previously reported, particularly over the proposed net pen location. The eastern corner of the proposed site is situated beside a depression that may accumulate deposition from a finfish farm and lead to localised high levels of enrichment. Monitoring at the nearby depression after three years at full feed discharge would determine if accumulation and excessive enrichment were occurring.

- A number of novel habitats and taxa were recorded in the current survey, but most were present at low densities or beyond the boundaries of the proposed site. Burrowing sea cucumbers were not observed in the present survey suggesting that this species is unlikely to be widespread in the vicinity of the proposed site. *Bispira bispira A* sabellid tubeworm beds appeared to be restricted to shell hash habitat in vicinity of the proposed farm and may be impacted by farm deposition. *Solanderia* hydroid trees were occasionally observed in the vicinity of the proposed site, however, they appeared to be low in numbers and more limited in extent than the communities found on the north eastern coast of Tory Channel.

- At feed inputs of 1600 t yr^{-1}, deposition is not expected to result in enrichment beyond the level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds (ES 5). The level of enrichment will improve rapidly with distance for the first 50 to 100 m, and then grade progressively to near-background conditions within ca. 500 m.

- The majority of the depositional footprint extends to north of the proposed net pens, and away from much of the potentially sensitive inshore reef area and the large tubeworm mound identified by O'Callaghan et al. (2014).

- Habitats inshore of the proposed farm were typical of Tory Channel and included reef communities that may be affected by farm deposition. While reefs in proximity to nearby salmon farms at Te Pangu and Clay Point have not shown farm-related impacts, some indications of enrichment have recently been observed. Due to the proximity of the proposed farm, the reef communities at Tio Point should be closely monitored.

6. ACKNOWLEDEMENTS

The authors thank Marc Jary for his assistance with the fieldwork, Eric Goodwin for running the depositional modelling, and Ben Knight for ADCP data analysis.

7. REFERENCES

Anderson TJ, Grange K 2013. Potential relocation of Site 8409, Oyster Bay: preliminary ecological survey. NIWA Client Report No: NEL2013-020.16 p.

Brown S, Ren J, Mackay K, Grant B, O'Callaghan J 2016. Benthic ecological assessments for proposed salmon farm sites. Part 2: Assessment of Potential Effects. Prepared for Ministry of Primary Industries. NIWA Client Report No: NEL2016-006. 65 p.

Cromey CJ, Nickell TD, Black KD 2002. DEPOMOD - modeling the deposition and biological effects of waste solids from marine cage farms. Aquaculture 214: 211-239.

Davidson R, Duffy C, Gaze P, Baxter A, DuFresne S, Courtney S, Hamill P 2011. Ecologically significant marine sites in Marlborough, New Zealand. Coordinated by Davidson Environmental Ltd for Marlborough District Council and the Department of Conservation. 172 p.

Davidson R, Richards L, Duffy C, Kerr V, Freeman D, D'Archino R, Read GB, Abel W 2010. Location and biological attributes of biogenic habitats located on soft substrata in the Marlborough Sounds. Prepared by Davidson Environmenal Ltd for the Department of Conservation and Marlborough District Council. Survey and Monitoring Report No. 575. 51 p.

Department of Conservation 1995. Guideline for ecological investigations of proposed marine farm areas in the Marlborough Sounds. 21 p.

Dunmore R 2016. Reef environmental monitoring results for NZKS salmon farms: 2015. Prepared for New Zealand King Salmon Company Ltd. Cawthron Report No. 283.18 p. plus appendices.

Forrest B, Cornelisen C, Clement D, Keeley N, Taylor D 2015. Monitoring framework for the Waikato coastal marine area: Report 2 - regional aquaculture monitoring priorities and guidance. Waikato Regional Council Report 2015/39 and Cawthron Report No. 2429. 67 p.

Henderson A, Gamito S, Karakassis I, Pederson P, Smaal A 2001. Use of hydrodynamic and benthic models for managing environmental impacts of marine aquaculture. Journal of Applied Icthyology 17: 163-172.

Keeley N, B., Forrest BM, Crawford C, Macleod CK 2012a. Exploiting salmon farm benthic enrichment gradients to evaluate the regional performance of biotic indices and environmental indicators. Ecological Indicators 23: 453-466.

Keeley N, Cornelisen C, Knight B, Taylor D 2015a. Monitoring framework for the Waikato coastal marine area: Report 3 - seabed and water column monitoring and standards. Waikato Regional Council Report No. 2015/40 and Cawthron Report No. 2546. 56 p plus appendices.

Keeley N, Gillard M, Broekhuizen N, Ford R, Schuckard R, Urlich SC 2015b. Best management practice guidelines for salmon farms in the Marlborough Sounds: Part 1: Benthic environmental quality standards and monitoring protocol (Version 1.0 January 2015). pp 32 plus appendices.

Keeley NB, Cromey CJ, Goodwin EO, Gibbs MT, Macleod CK 2013a. Predictive depositional modelling (DEPOMOD) of the interactive effects of current flow and resuspension on ecological impacts beneath salmon farms. Aquaculture Environment Interactions 3: 275-291.

Keeley NB, Forrest BM, Macleod CK 2013b. Novel observations of benthic enrichment in contrasting flow regimes with implications for marine farm monitoring and management. Marine Pollution Bulletin 66: 105-116.

Keeley NB, Macleod CK, Forrest BM 2012b. Combining best professional judgement and quantile regression splines to improve characterisation of macrofaunal responses to enrichment. Ecological Indicators 12: 154-166.

MacDiarmid A, Bowden D, Cummings V, Morrison M, Jones E, Kelly M, Neil H, Nelson W, Rowden A 2013. Sensitive marine benthic habitats defined. Prepared for the Ministry for the Environment. NIWA Client Report No. WLG2013-18. 68 p. plus appendices.

MPI 2013. Literature review of ecological effects of aquaculture. Ministry of Primary Industries, Wellington.

O'Callaghan J, Grange K, Ren J, Sykes J 2014. Site assessment for potential finfish site: Oyster Bay. NIWA Client Report No. NEL2013-020. 26 p.

8. APPENDICES

Appendix 1. Enrichment Stage background.

Deposition of organic material from aquaculture farms changes the amount of nutrients arriving at the seabed, which can change the abundance and types of the biological communities that live on and in the seabed. In the case of finfish farms, deposition of feed and fish faeces results in high levels of organic enrichment, which in turn leads to depletion of oxygen within sediments and changes in sediment chemistry (e.g. increases in sulphides).

There are numerous single measures and indicators that can be calculated for describing effects of aquaculture. However, they all respond differently to aquaculture activities, thereby complicating their application within a compliance and adaptive management framework. The need for a single, robust measure for managing aquaculture consents led to the development of the Enrichment Stage (ES) methodology (Keeley et al. 2012a; Keeley et al. 2012b), which integrates multiple measures of the biological, chemical and physical changes that occur within sediments located in the depositional footprint of aquaculture farms. The ES methodology is grounded in the well-known concept of ecological succession in stressed environments and organic enrichment gradients used in developing benthic health indices around the world. The end result is an 'overall ES score' that captures the full range of possible enrichment effects for soft sediment habitats in a single measure; i.e. from pristine natural conditions (ES = 1) to extremely enriched and impacted conditions (ES = 7; Figure 2).

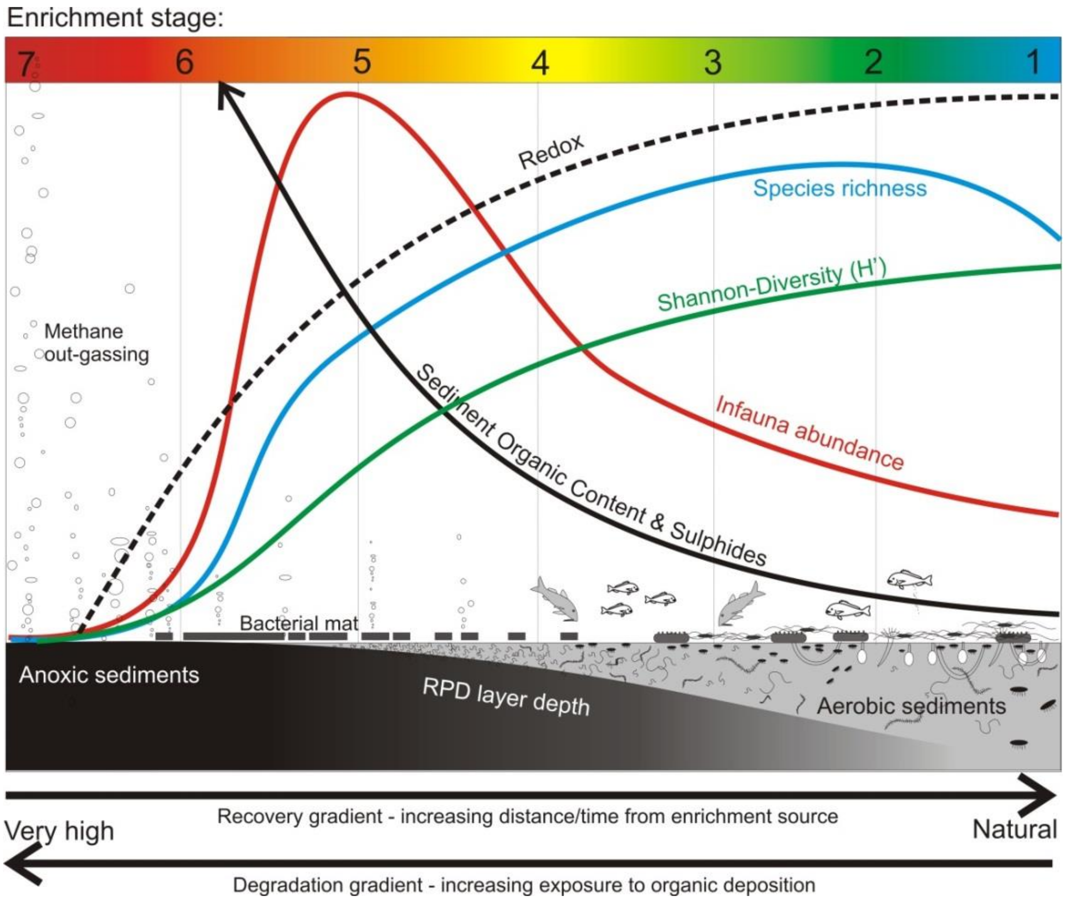


Figure A1.1. Stylistic representation of the enrichment stage (ES) gradient with typical responses of individual variables according to proximity to a source of organic enrichment (to the left). The overall ES score integrates these variables within a single value on a scale of 1 (natural conditions) to 7 (extremely enriched).

An important feature along the ES gradient is the stage of peak infaunal abundance (ES 5). Under these conditions, one or a few enrichment-tolerant 'opportunistic' species (e.g. capitellid worms and nematodes) tend to proliferate. At this stage, the benthos is still considered biologically functional and is often associated with the greatest biomass (Keeley et al. 2013a) and, therefore, the greatest waste assimilation capacity. Enrichment stages greater than ES 5 are characterised by very highly enriched sediments, becoming excessively enriched at ES 6; it is at these stages that the infaunal communities tend to collapse, with waste metabolism declining abruptly and organic accumulation exacerbated. For these reasons, ES 5 is recommended as the upper level of acceptable seabed effects beneath salmon farms in the Marlborough Sounds (Keeley et al. 2015b).

The ES is calculated by measuring a suite of widely-used benthic indicators and biotic indices that contribute to (and complement) the ES score (Keeley et al. 2015b). Important contributors to ES scores include measures of organism abundance and the diversity of communities living on and within the sediments. These organisms are referred to broadly as macrofauna, and infauna for those living within the sediments. Measurements of indicators and biotic indices are used to calculate scores on an equivalent ES scale (1 to 7) for three categories: organic enrichment, sediment chemistry, and macrofauna. These are then given weightings and combined to calculate an overall ES score for a given location (see Section 2.4).

The ES methodology has been adopted in the BMP guidelines for managing benthic effects from salmon farms in the Marlborough Sounds (Keeley et al*.* 2015b). Its application requires a number of steps, including estimating the depositional footprint of a farm and positioning monitoring sites along a gradient from the farm to the outer zone of likely effects. The overall ES score can be assessed against standards for these locations (e.g. ES must be < 4 beyond a set distance from a farm). In some cases, standards may also be set for individual indicators or parameters (e.g. levels of trace metals and sulphides). Individual variables and indictors that contribute to the overall ES score have value in their own right, and play an important role in interpreting results, making the ES methodology a ‘weight of evidence’ approach.

More information can be found in the Ministry for Primary Industries Aquaculture Guidance series on line (MPI 2013; http://www.mpi.govt.nz/) and in recent Waikato Regional Council reports (Forrest et al*.* 2015; Keeley et al*.* 2015a).

Appendix 2. DEPOMOD parameters and settings.

DEPOMOD parameters and settings used to estimate flux to the seabed environment from the Tio Point site.

Grid generation	
Major grid size	99 x 99 at 10.2m * 10.2m (1010m x 1010m)
Minor grid size	99 x 99 at 9.0m * 7m (891m x 693m)
Position on grid	12, 18
Minor origin	2614398, 5994827
Cage configuration	1 row of 4, 300°
Total number of cages	4
Spacing between cages (m)	40
Cage orientation (deg T)	40°
Depth under cages (m)	16
Particle Tracking	
Type of feed release	Continuous, constant
Food loading (t yr^{-1})	1000, 1200, 1600, 2000, 4000
Cage dimensions (m)	40 x 40 x 20 deep
Source of current velocity data	RD Instruments ADCP
Current depth bins used (m)	2, 10, 18, 26, 34 m above bed
Instrument sampling period	Every 10 min
Time step used in model (sec)	3600 sec (1 hr)
Length of velocity record (hr)	1031 hr (43 days)
Random walk model	.1,.1,.001
Sinking rate for feed	9.5 cm/s
Sinking rate for faeces	3.2 cm/s
Water content of feed	10 %
Digestibility	85 %
Waste rate	3 %