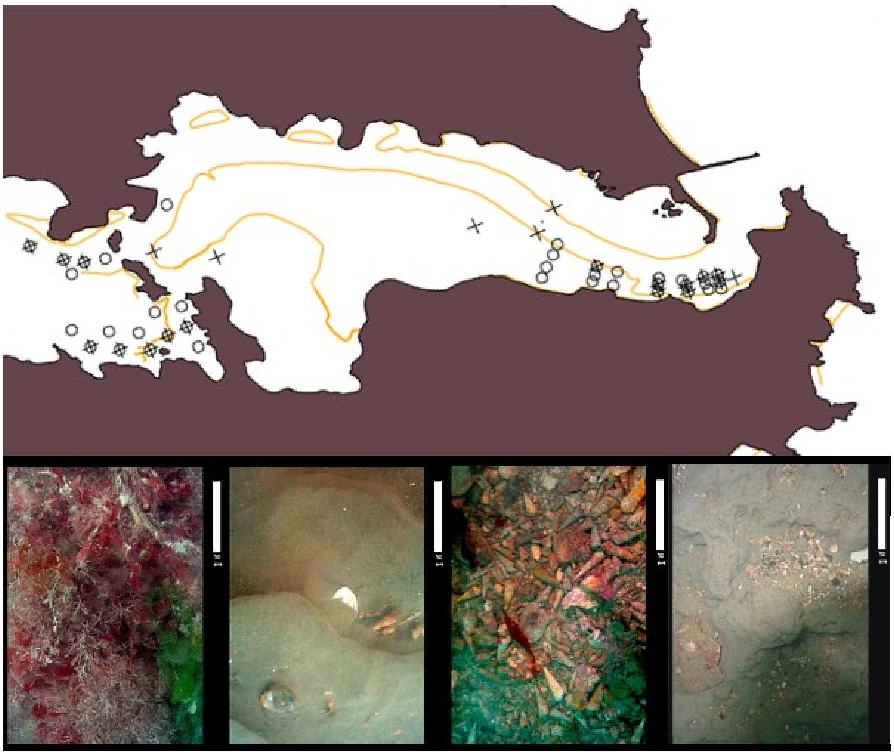
Benthic Habitat Structures and Macrofauna of Otago Harbour: Supplemental Information from *Te Rauone* Beach and Latham Bay



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Macrofauna of Otago Harbour: Supplemental Information from *Te Rauone* Beach and Latham Bay

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Executive Summary

Port Otago Limited (POL) is considering a proposal to modify the primary shipping channel in Otago Harbour, Dunedin, New Zealand. These capital dredging works are proposed in addition to the present maintenance dredging programme in order to accommodate larger vessels travelling between the harbour entrance at *Taiaroa* Heads and Port Chalmers.

POL commissioned a study in 2008 to investigate the physical appearance and biological communities present on the seafloor of the lower Otago Harbour which may be affected by the proposed operations. The report was part of a collection of documents which examined different aspects of the harbour environment and relevant processes. The present study was conducted by Benthic Science Limited in June and July 2009 to extend study coverage into areas of interest identified through a consultation process. Subtidal and low–mid intertidal areas near *Te Rauone* Beach, Latham Bay, Edwards Bay, and the shipping channel near Sawyer's Bay were sampled.

Combined with the previous work, the present study represents the most comprehensive habitat mapping exercise undertaken in the Otago Harbour. The studies undertook two principal activities. The first was a photographic survey of benthic (seafloor) features to identify basic physical and biological characteristics. The second exercise collected benthic samples to examine smaller (near microscopic) animals (macrofauna) in an effort to identify distinct biological communities or species with limited spatial distribution. These data were combined to provide an integrated, spatially-oriented understanding of the harbour within which other studies and anecdotal observations can be used to more effectively inform management decisions.

2009 Photographic Survey

Five photographs of the seafloor (about 300 × 300 mm) were taken at each of 25 additional sites near the harbour entrance between the northern end of *Te Rauone* Beach and Akakorako Point. Nineteen more sites were visited near the boundary with the upper harbour. Because some 2008 sites were revisited, a total of 147 discrete survey areas were examined in the combined mapping exercise. Eight transects of five to eight sites were located across the

primary shipping channel in order to characterise the channel bottom, slopes, and adjacent areas. The remaining sites were placed, according to available information, to include all lower harbour depths in two metre intervals and to include at least one site within every square kilometre.

The lower Otago Harbour seafloor is a patchwork of different habitat types. The photographs were reviewed and placed into eleven categories according to the biological and physical features which dominated each site. These categories were then simplified to seven based on the organisms and evidence of dominant forces (such as currents, sediment deposits, etc.) present at each site. One additional benthic structural class has been added to the classification scheme presented in the 2008 report[1]. These seven categories were:

- Sandy bottom with sparse shell and algae (when present), no current features
- Sandy bottom free of attached algae and obviously rippled by currents
- Extensive algal mats (seabed often not visible)
- Inlet-like areas with seagrass, living or empty cockle shells, ghost-shrimp mounds, and/or lugworm mounds and variable amounts of algae
- Muddy sand to muddy areas with extensive mats of animal tubes, sparse algae, and few large shells
- Rocky or shell deposit areas with prominent sessile (attached) animals, such as sponges, hydroids, and tunicates, often mixed in with attached algae, rocks or shells are encrusted with coralline algae.
- Mudstone or consolidated clay pavement (flat or sculptured) with pockets of coarse sand or shell.

Observations near *Te Rauone* Beach indicated that pavement-like seabed features extend from the Entrance Spit past Weller's Rock. A medium-sand bank on the southern side of the channel margin forms a retention structure for muddier sand, tube mats, and a sparse patch of horse mussel (*Atrina zelandica*). Horse mussels are uncommon in the harbour, but known from the adjacent shelf environment outside of the harbour.

Observations near Latham Bay and Sawyer's Bay did not reveal any new habitat types. Deeper Latham Bay is characterised by algal patches or rippled sand bottom in areas of higher tidal flow. Shell deposits are present in the tidal narrows between Quarantine Island and the Portobello Peninsula and between Quarantine and Goat Islands.

Algal mats were the most spatially extensive habitat type, forming about 29% of the categorised area. Inlet features (28%) were just as common, while rippled sand (13%), and other categories were less extensive. Every habitat type was found adjacent to every other habitat type. The habitats were patchy on the scale of 10s to 100s of metres with the exceptions of extensive rippled sandy patches on the channel margins adjacent to Deborah Bay and the inlet-feature band on the northern side of the channel from Pulling Point to Aramoana and on the central sandflat (where it intermingled with algal patches).

Macrofauna Sampling

In the 2008 work, lower harbour areas with soft sediments categorised in the photo survey were divided into grid cells of about 136 × 136 m. Sample sites were randomly located according to the size of each area. A total of 105 benthic grab samples (0.05 m^2 each) were collected throughout the lower harbour. This random assignment within survey areas prompted the 2009 investigation of an area sparsely sampled near *Te Rauone* Beach. The additional sites were located to sample estimated bathymetric intervals in a uniform fashion. Animals were sieved out of the samples and those retained on a 1 mm mesh were examined. Over 33,000 animals were identified among 190 taxa in the combined work. Patterns of abundance and diversity of the most numerous mollusca, crustacea, and worm taxa were examined individually and collectively. Macrofaunal samples from *Te Rauone* Beach contained, on average, more individuals and more taxa (higher diversity) than Latham Bay samples. No taxa were encountered that were not previously identified from elsewhere in the harbour. The distribution of these animals was also examined with respect to habitat classification using both seven and eleven category schemes. While abundance and diversity values differed throughout the study area, no distinct macrofaunal communities were identified. No clear pattern was found relating habitat type to soft-sediment macrofaunal composition despite extensive sampling.

Conclusions

The lack of distinct macrofaunal communities is probably a realistic reflection of the patchy (metre scale) benthic habitats of the harbour. Samples taken tens of metres apart were often as similar as those taken thousands of metres apart. Most sites shared most taxa. With respect to macrofaunal species, the lower harbour appears to consist of one spatially variable, but cohesive community. Dredging operations could be expected to directly alter portions of the lower harbour channel bottom and margins from one of the existing types to another, but are unlikely to create new habitat types or eliminate any existing type. The potential impact of any possible increased suspended sediment load is beyond the scope of the present work.

Abstract

Port Otago Limited is proposing to modify the primary shipping channel in the lower portion of Otago Harbour, Dunedin, New Zealand. This report forms one portion of the impact assessment work. The purpose of this study was to define spatial patterns of seafloor habitat structure and macrofaunal communities in some areas not previously examined. A photographic survey of the benthos was conducted to analyse benthic structure. The outer harbour benthos is comprised of at least six to eleven broad habitat classes dominated by medium sands with a variable overburden of relict shells and extensive sand flats supporting a sheltered inlet seagrass community. Thick algal beds are present in approximately 29% of the study area. Proposed channel modifications intersect areas coincident with each habitat class. Macrofaunal samples were analysed from 17 additional locations within the harbour. A total of 122 macrofaunal samples were analysed in the combined 2008/09 studies. Analyses indicated that macrofaunal distributions did not correspond to benthic structure classes . Furthermore, distinct assemblages of annelids, arthropods, and molluscs were not found. At the current level of taxonomic detail, the macrofaunal data provide evidence that soft sediments of the lower harbour may operate as one spatially variable, but cohesive community. Sub-metre bathymetry in the extensive shallow regions of the lower harbour probably contributes to patchiness of the benthos, especially the propotion of seagrass (*Zostera muelleri*) to algal patches. The present work represents the most spatially extensive benthic study undertaken in the harbour and provides support information for management with the best available data..

Introduction

Port Otago Limited (POL) is the corporate body primarily responsible for commercial shipping operations within Otago Harbour, adjacent to Dunedin, New Zealand. POL is undertaking several studies of the lower harbour to understand the connectivity of existing harbour communities to inform operational decisions, specifically modifications to the shipping channel. Proposed channel modifications (dredging) are proposed to accommodate the next generation of larger container ships.

The present work contains the principal findings of surveys conducted in 2009 to supplement previous survey work[1,2]. This is a technical report of research findings only. As it is written for a restricted and informed audience, no attempt has been made to include a comprehensive literature review. This study focused on subtidal and low- to mid-intertidal habitats.

Anecdotal evidence, unpublished reports[1,2], and prior published works[,3,4, 5] suggest that the lower harbour benthos is a mosaic of habitats of diverse substratum structures, physico-chemical properties, and water flow[6] conditions supporting distinct macrofaunal communities which must be considered with special respect to proposed dredging operations and projected suspended sediment loads[7]. The present work aims to add to our overall understanding of the harbour benthos in a spatially integrative manner. An understanding of community composition and connectivity is an important part of the channel modification planning process.

Several benthic environments including muddy sand, seagrass, shell hash mounds, and cobble expanses were known to exist in the lower harbour. Seabed images were collected to support a coarse classification of the seabed according to apparent physical and biological features. A set of categorical variables and expert analysis of habitat types was established in prior work[1]. The present study attempted to integrate new sample areas into the existing overall view. In addition to the gross structural map of the benthos produced from the imagery, sediments from several areas were collected to examine the macrofaunal component of the seabed community.

Methods

Photo Survey Locations

Thirty-eight sites were surveyed in areas not covered by the 108 survey sites sampled in the prior benthic imagery survey (Figure 1). Recent (2003) decimetre-resolution bathymetry from regular channel dredging operations was made available by POL, but detailed bathymetric data were not available for the extensive areas beyond the channel. Rough depth values were estimated from NZ nautical charts interpolated between soundings on a 100 × 100 m grid (data provided by NIWA, Figure 2).

Photographic survey points focused on two areas of interest. One area comprised the southern channel margin between *Te Rauone* Beach and *Akakorako* Point. These samples have been identified as coming from *Te Rauone* Beach in this report. The other areas of interest included Latham Bay, Edwards Bay, and a portion of the shipping channel between Goat Island (*Rakiriri*) and Sawyers Bay. These sites form the primary water exchange areas at the boundary between upper and lower portions of the harbour. These three areas have been collectively referred to as 'Latham Bay' samples in this report.

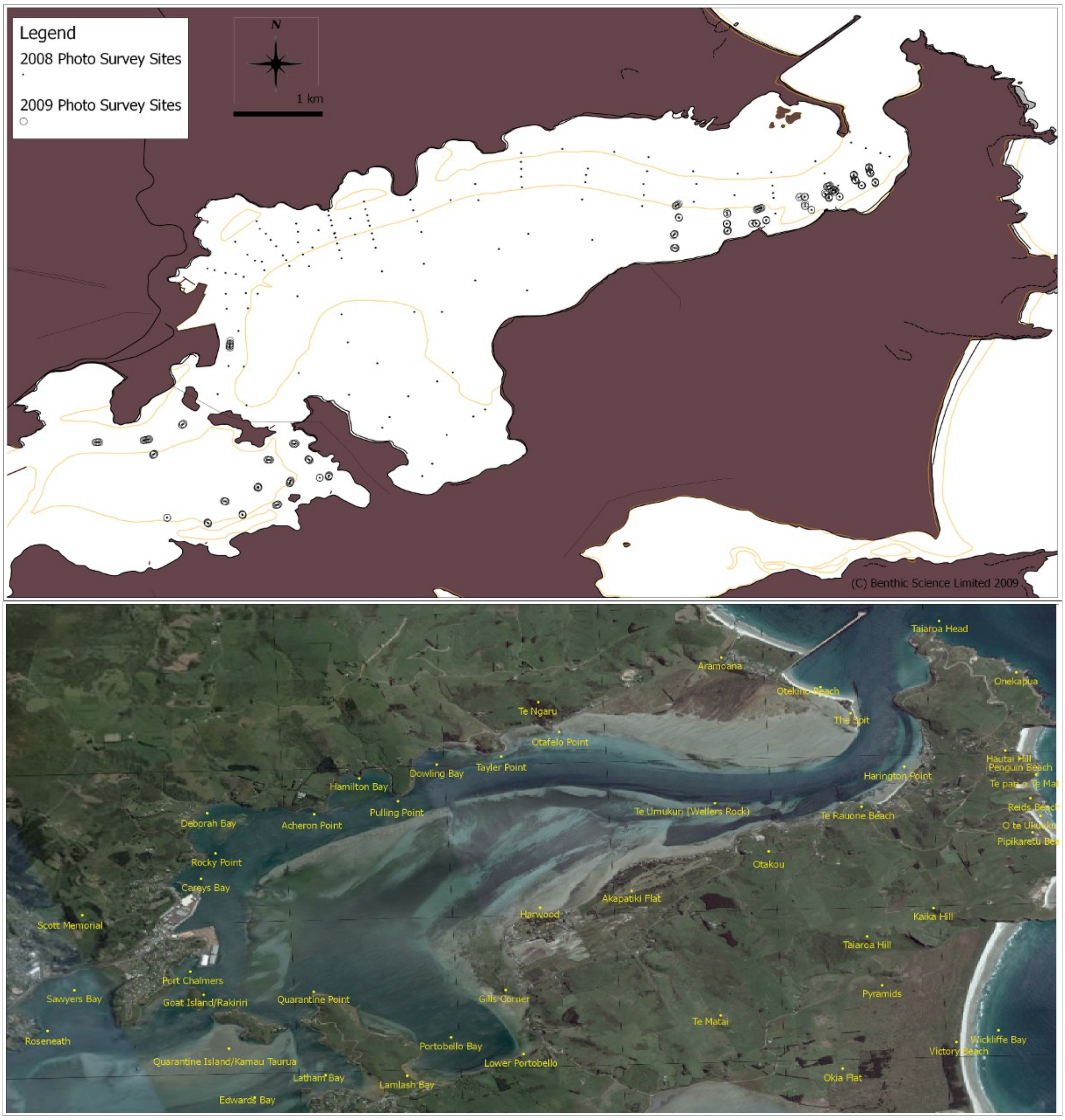

Figure 1. Photographic survey sites in Otago Harbour (top panel): open circles indicate photo sites from the present survey while dots identify previous photo sites[1], areas outlined in yellow represent shallow areas including sandflats exposed at low water. Place names (bottom panel, LINZ 2009) used in the present study (background image from Digital Globe 2008).

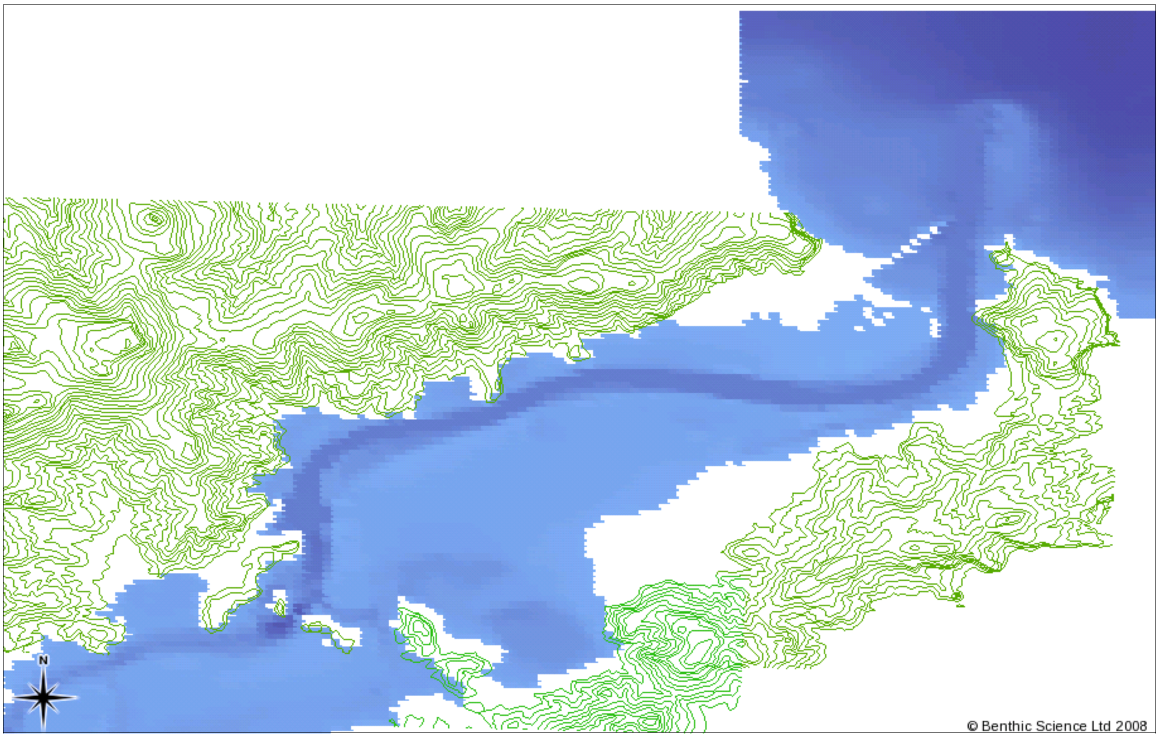

Figure 2. Generalised bathymetric data for the study area (depth in centre of each 100 × 100 m grid cell) presented as a gradient from 0 (white) to 28 m water depths (deepest blue) with respect to chart datum.

Image Acquisition

An underwater camera in a weighted frame was deployed from the *M/V Nemo*, a 5 m vessel equipped with a GPS (Garmin 76CSx) and sounder (Navman Fish 4500). The imaging system utilised a Canon Powershot G2, 4.0 megapixel digital camera which allowed live-video preview on a shipboard computer. A total of 217 images, each covering an unobstructed area of 400 × 300 mm ($0.12\ m^2$), was acquired over three field days, 11, 12, and 24 June 2009.

The same photographic methodology was employed on all surveys. As the vessel approached a site, the camera was manually lowered to just above the seabed as the vessel actively held position with the tether vertical. The camera was then lowered onto the seabed and slack was played out on the tether. After the first photo was taken, the camera was lifted just off the bottom while the vessel was allowed to drift with prevailing conditions. Photos were taken after each approximately 10-20 m of travel and the vessel repositioned if necessary. Thus a particular site was represented by a series of five photos taken between 60 and 130 m of each other along the current axis. Practically, all photos were taken within 30 m of the geographic site position. Vessel track points (Figure 3) indicate the pathways casually observed directly and through the benthic video feed.

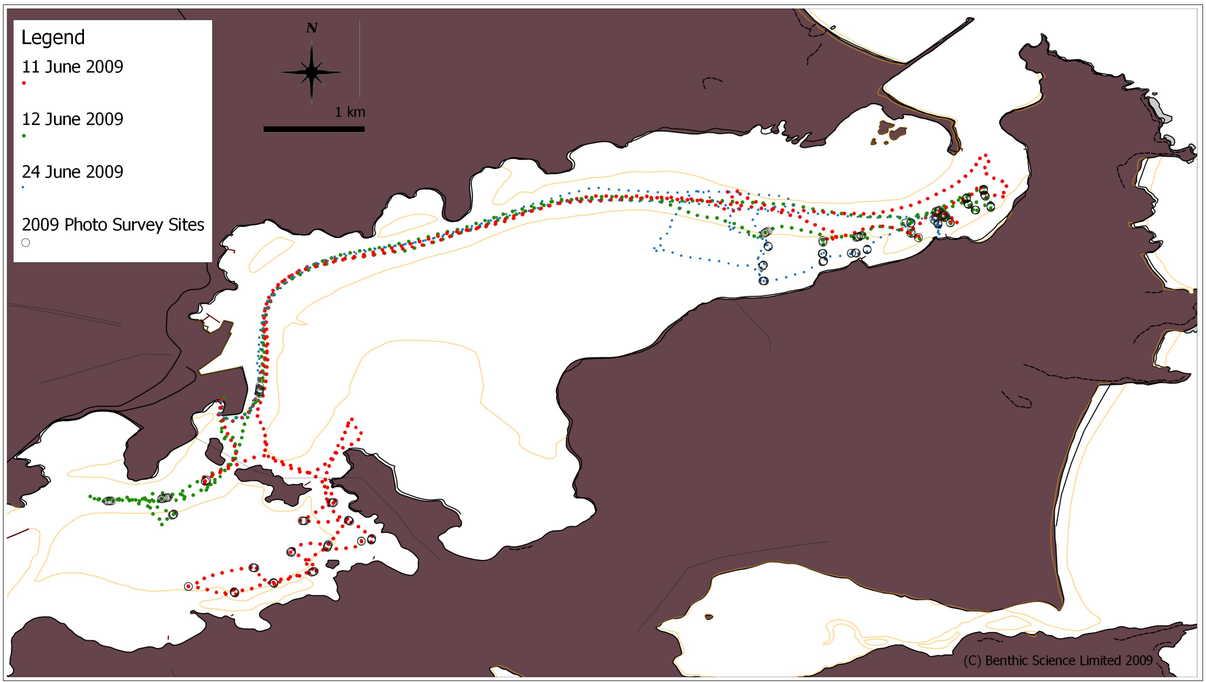

Figure 3. Vessel survey tracks on 11 June 2009 (red), 12 June 2009 (green), and 24 June 2009 (blue) in relation to 2009 photo survey sites (open circles). Seafloor observations were frequently made along this track.

Image Analysis

Although artificial lights were used in dark portions of the channel, most images were illuminated by natural light. Marks along the frame skids allowed size reference in the fixed focal plane for each photo. Images were automatically contrast and colour-corrected in a batch process using Photoshop v6.0 (Adobe, Inc.) using fixed black and white standards on the skids. Another batch process masked the seafloor area of interest from skid obstructions and placed a 10 cm scale and black border on each image. Analyses were therefore conducted using images of the same area and contrast.

Categorical habitat variables, determined *a priori*, were evaluated for each image (Table 1). The variables were chosen to represent a structural assessment of the physical environment expected to influence fauna through water flow alteration, surface area, and macrofaunal refugia. When visible, substratum type was classified according to primary (>50% of visual field) and secondary (>20%) characteristics[6]. Shell condition was intended to identify whether flow and sedimentation characteristics in shell lag areas permitted encrusting coralline algae growth and retention on the surface over a period of several years or if lags were the product of recent processes like storm events which frequently deposit large numbers of *Zethalia zelandica* shells on nearby shores. Living cockle abundance (a continuous variable) was determined by counting visible siphons. As algae typically formed multi-species aggregations it was not feasible to identify individual taxa from most photos. Instead, the presence of basic algal structures were identified. Blade algal presence was almost entirely due to *Ulva* sp. (*Undaria pinatifida* was occassionally observed, *Macrocystis* observations were uncommon) while filamentous and macrothallus alga were represented by several species. The presence of large (>1 cm) burrows, conspicuous sponges and the tunicate *Pyura pachydermatina* were recorded and must be considered to be conservative variables since many were hidden under or within features when viewed from above.

Expert habitat descriptions of each site (a composite of all images collected at that site) were also collated. The review resulted in eleven distinct apparent habitat types. Images were reviewed for a third time in comparison to the types identified based on broad biophysical considerations. For example, areas of bioturbated muddy sand covering relict snail (*Maoricolpus roseus*) shells and sparse patches of one algal species was considered to be a single state of a more general condition that included another site with relict snail (*Turbo* sp.*),* cockle (*Austrovenus),* and *Cominella* shells clearly transported from other areas in the harbour interspersed with sparse drift algae (Figure 4a). Five of these classes could not be heuristically separated between repeated examinations, therefore a second set of seven broader habitat classes were constructed (Table 1).

Macrofauna were conspicuous in several images including the crabs *Macrophthalmus hirtipes* and *Nectocarcinus antarcticus,* the mantis shrimp *Heterosquilla tricarinata,* and many unidentified hermit crabs (Paguridae). Small fish, most notably the triplefin (*Tripterygion varium),* were frequently recorded. Several snails were common including *Turbo smaragdus, Micrelenchus tenebrosus, Stiracolpus symmetricus,* and *Maoricolpus roseus.* Less common was the tunicate *Ascidia adspersa*, sponges including *Tethya* sp., and several limpets, chitons, barnacles, and serpulid polychaetes (likely *Galeolaria* sp., *Pomatoceros ceruleus*, and *Spirorbis* sp.) attached to shells. Sea stars including *Ophiomyxa brevirima, Asterina regularis, Allostichaster insignis* and one unidentified species were observed. With the exception of the sea tulip *Pyura pachydermatina*, only qualitative macrofaunal observations were based on the photo survey data. While resolution may be adequate for identifying animals exceeding several centimetres in size, the difficulties of detecting individuals in complex habitats require a per-unit-effort approach deemed inadequate for the number of images collected in the present study. An example is given in Figure 5a where an asteroid and ophiuroid can be clearly identified in a complex algal habitat, but the sabellid polychaetes are easily overlooked. Even large animals like the portunid crab (Figure 5b) can be overlooked due to image complexity. The grab samples were analysed to provide quantitative macrofaunal data from soft-sediment areas.

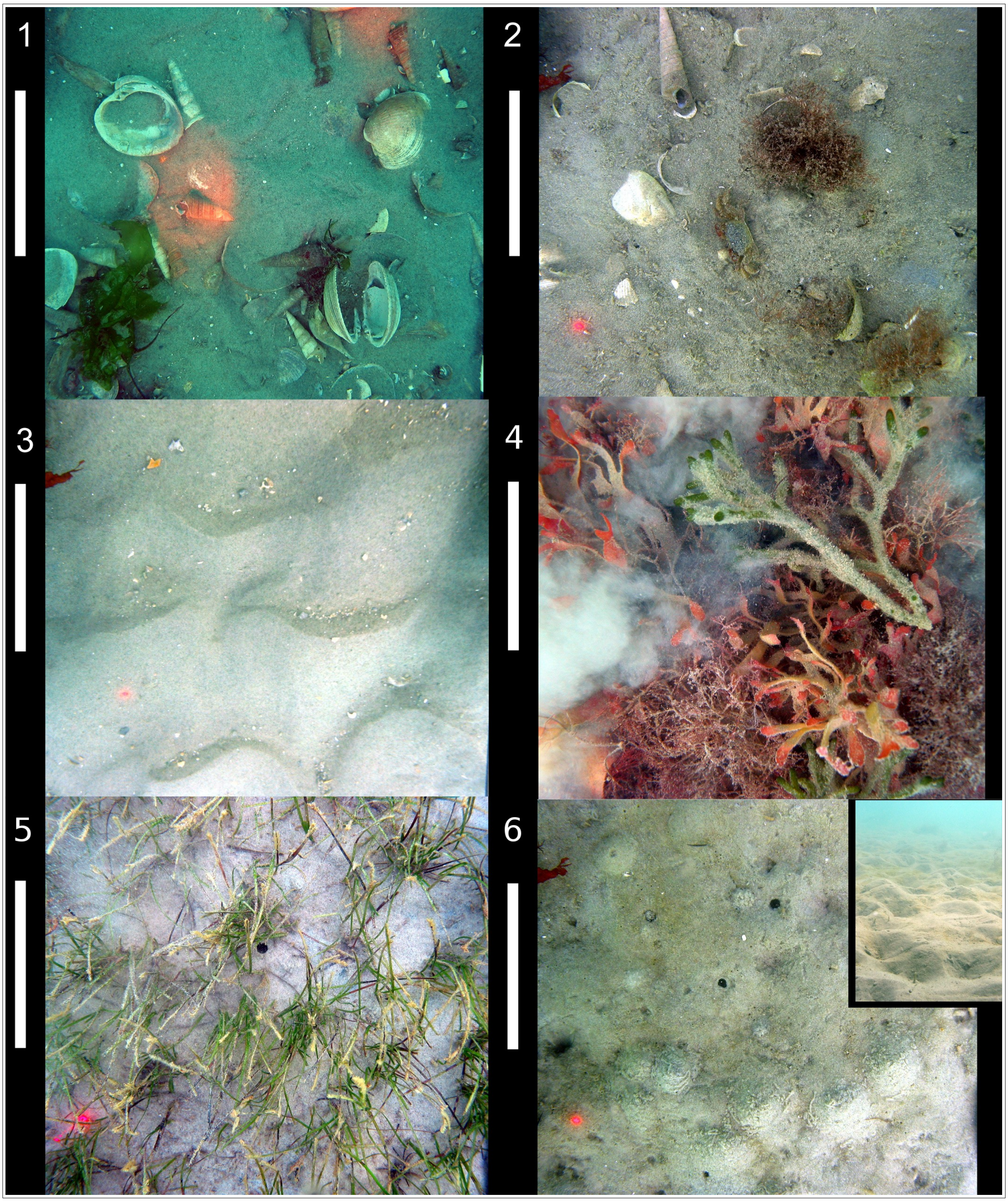

Figure 4a. Representative diversity of benthic structural classes 1-6 within the eleven benthic structure class scheme. Scale bars = 10 cm, see Table 1 for brief descriptions. (The inset image in panel 6 is an oblique view of the habitat showing vertical relief not apparent in the plan view.)

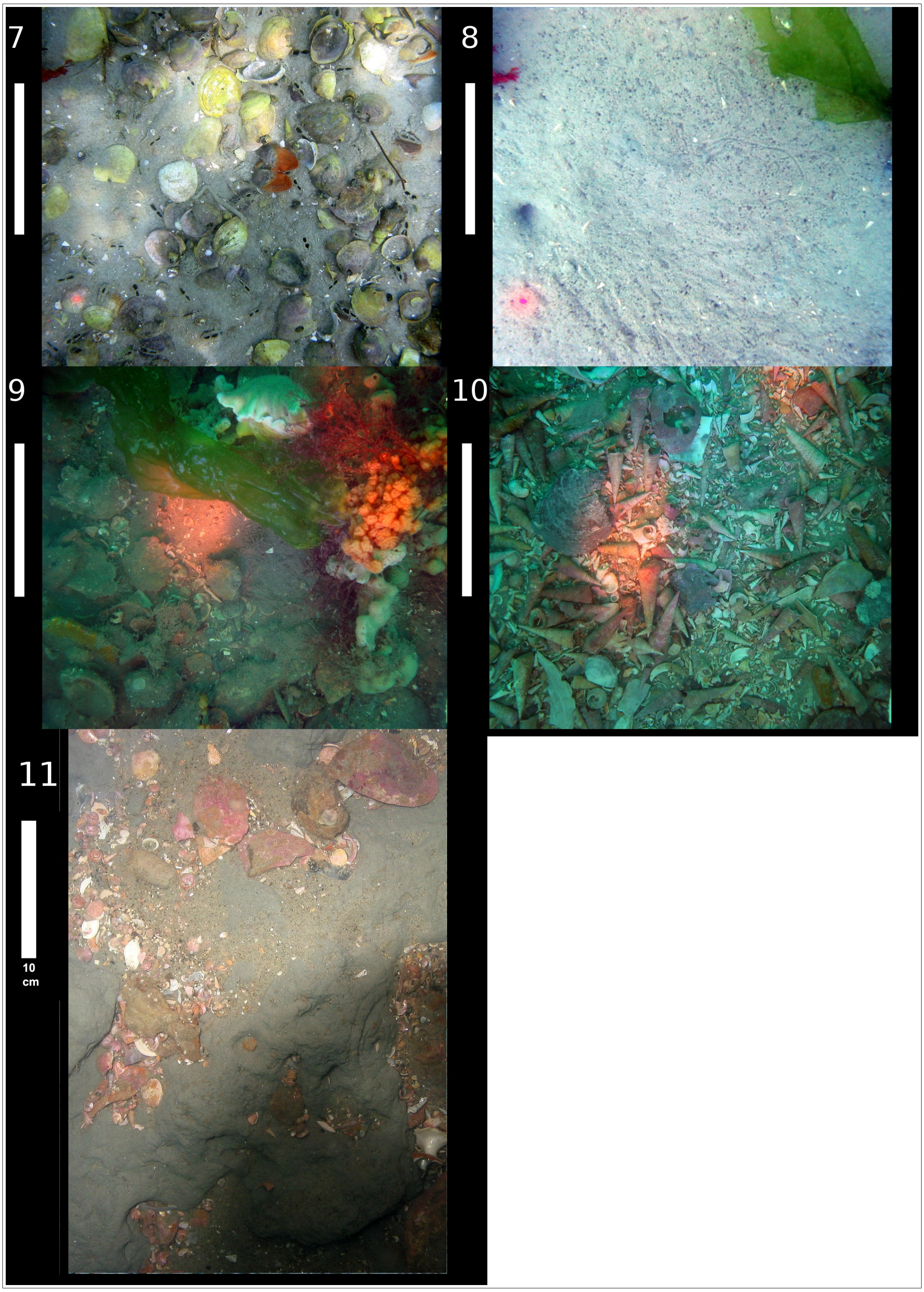

Figure 4b. Representative diversity of benthic structural classes 7-11 within the eleven benthic structure class scheme. Scale bars = 10 cm, see Table 1 for brief descriptions.

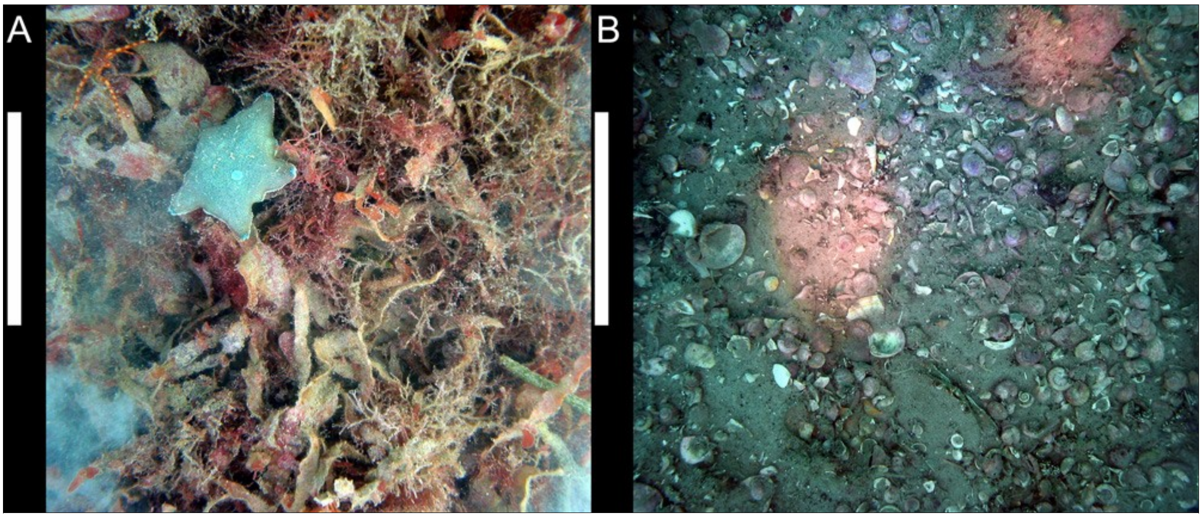

Figure 5. Macrofauna were not formally analysed in the photo survey due to the complexities of several environments. *Ophiomyxa brevirima* and *Asterina regularis* can be seen in panel A, but small sabellid polychaetes are easily overlooked. Even large animals like the 9 cm portunid crab visible in panel B are easily missed. Scale bars = 10 cm.

Table 1. Objective and subjective categorical evaluations of benthic images.

Variables evaluated for each image	-Dominant sediment forces - Physical (sand ripples, other indications of high flow rates) or Biological (bioturbation evident or substratum mostly covered by algae). -Substratum Visible? (Y/N) -Primary substratum type (muddy sand, sand, cobble, shell, mudstone pavement) occupying >50% of the field -Secondary substratum (muddy sand, sand, cobble, shell, mudstone pavement) occupying >20% of the field -Shell condition (recent or relict) as determined by degree of fracture, wear, and encrusting algae -Living cockle abundance (determined by the number of visible siphons) -Blade algae present. -Filamentous algae present -Macrothallus algae present -Encrusting corraline algae present -Seagrass (*Zostera* sp.) present -Sponge present -Macrofaunal burrows present (large features evidence of, *e.g., Macrophthalmus hirtipes*, *Macomona liliana, Callianassa filholi*, *Abarenicola affinis*, and Stomatopoda. Numerous small burrows of polychaetes, amphipods, and tanaid shrimp were not considered here) -*Pyura pachydermatina* (Sea tulip) present -Usability, an image was not evaluated if both frame skids were not in firm contact with the seafloor, the image was blurred, too dark, or showed signs of experimental artifact like skid marks, tether destruction, etc.
Superficial benthic structure classes	1 - Medium sand with sparse patches of algae (mostly drift), relict shells (when present) 2 - Medium sand with sparse patches of algae present, a silty or floculent layer is present and few sand ripples are present, sediments surface indicates recent bioturbation, relict shells (when present) 3 - Medium sand with current-formed ripples (only ripples with a wavelength of <240 mm were likely to be detected), little or no bioturbation, no algae, few (if any) recent or relict shells 4 - Thick algal mat or areas where patch coverage substaintially exceeds bare sand, usually of several species 5 - Seagrass (*Zostera* sp.) on medium sand, algae was almost always present in small amounts, algae increasing with water depth until replacement. 6 - *C. filholi* mounds, *A. affinis* fecal casts, stomatopod burrows present, indications of burrowing bivalves (if present) minimal or uncertain, typical community of seagrass margins. 7 - Cockle beds were indicated if siphons of living animals were observed or living shells. 8 - Dense macrofaunal tubes likely formed by polychaetes, amphipods, and tanaids. Large bioturbators move 'chunks' of sediment suggesting that biota substantially altered fabric. 9 - Deep habitat with cobble-sized stones and mollusc shells fused together by coralline algae, tunicates (including *P. pachydermatina* and other spp.), hydroids, and sponges are evident. Environment shows signs of high water flow (little or no fine sediment, robust sessile invertebrates and algae dominate) 10 - Shell hash, mostly of gastropods including *Maoricolpus* sp., most sites were dominated by a small group of species (e.g. *Paphies, Zethalia zelandica)* and sub-fossil bivalves. 11 - Mudstone or consolidated clay pavement (flat or sculptured - impenetrable by grab)
Reduced set of classes (combined categories above)	1 - Sand with varying silt/diatomaceous film cover, sparse algae, few shells (consolidating 1, 2) 2 - Rippled medium sand (3) 3 - Algal mats or dense patches (4) 4 – Interdigitated inlet features (consolidating 5, 6, 7) 5 - Tube mats (8) 6 - Shell hash or deep sessile community with cobbles and/or fused shells (9,10) 7 – Mustone or consolidated clay pavement (11)

Macrofaunal Sampling

The positions of macrofaunal samples were placed to include areas not examined in prior work and to sample bathymetric intervals of approximately 2 m (Figure 6). Sediments were collected on 11, 12, and 24 June 2009 from the *M/V Nemo* with a standard ponar grab (sampling area of 0.05 m^2). A sample was rejected and the site resampled if less than 30 mm of sediment (grab centre) was recovered or grab closure was obstructed by debris. A sampling site was abandoned after three failed attempts. The contents of each grab were removed to pre-labelled bags. Samples were kept cool until landed (within 5 h).

Figure 6. Locations of grab samples (crosses '×') collected in June 2009 compared to those collected in 2008 (small plus '+' signs).

Macrofaunal Processing

Animals were separated from most sediments by a combined elutriation and sieving protocol. This process was intended to provide a standard level of capture efficiency while minimising mechanical stress on the biological material to aid identification and curation. On shore, each sample bag was opened. Buffered formalin was added in sufficient quantity, dependent upon the water content and apparent organic content of the samples, for adequate fixation. The samples were held in a cool, dark location for 1-3 days prior to further processing in the laboratory. After that time samples did not present indications of acidification. Several litres of freshwater were added to each sample bag to dilute the fixative and suspend delicate animals. This supernatent was then poured into a pre-wetted 1.0 × 1.0 mm aperture mesh sieve. The process was repeated. If macroalgae was present in the sample it was manually extracted, washed over the sieve, and stored separately. The 1.0 mm sieve residue was gently washed into a small pottle with 70% ethanol with water. The remaining content of the sample bags was then washed into a plastic tray. Several litres of freshwater were added and the sediments agitated to suspend non-mineralised organisms before being decanted into the sieves. This process was repeated and animals were again washed into a small pottle. Finally, the entire sample was sieved.

One sample (TR06) was evenly split and each split was processed separately in order to assess the possibility of processing less material and extrapolating macrofaunal abundance. Several taxa were unique to each split and low abundances among the more numerous taxa indicated that splitting was not desirable. The entire grab sample from each sites was therefore processed. Unless specified otherwise, macrofaunal abundances were reported as the number of individuals per 0.05 m^2.

Samples were manually sorted to the lowest readily identifiable taxon by experienced technicians in small aliquots using a stereomicroscope. Taxon counts were entered into a database using the BioTally system (Benthic Science Limited 2007). Samples were curated to the replicate level for taxonomic analyses and archival purposes. All algal surfaces were examined under a microscope and unattached animals were removed for macrofaunal analysis. Attached epifauna consisting of bryozoans, tunicates, serpulid polychaetes (*Spirorbis* sp.), hydroids, and sponges were not removed for enumeration.

The counts presented in this report represent identifications with varying levels of taxonomic detail as dictated by pragmatic considerations. Whenever statistical comparisons have been made between macrofaunal data collected in 2008 and 2009, the analyses were conducted on a derived data set which represents the highest resolution common denominator. For example, in 2009 the syllid polychaete *Exogone sexoculata* was readily differentiated from two other *Exogone* taxa, but in 2008, specimens were only identified to genus, therefore abundances from all *Exogone* taxa were combined in the derived data set. Biological material (excluding algae) has been curated and stored.

Data Analyses

Data from images were stored in a PostgreSQL v8.2 database for possible later analysis with macrofaunal and geochemical data. Geospatial plotting was done using QGIS v1.0.2[5] operated within a Mandriva Linux environment. Grid systems of coastline and bathymetric data were converted to WGS84 datum for comparison with data from the present study.

Where animal densities are reported as individuals m^{-2} the values have been extrapolated from the actual sample area under consideration. All faunal data reflect abundances except for colonial animals (bryozoans, hydroids, porifera, etc.) where presence only was recorded.

Statistical analyses were conducted using the Primer 6.1.5 application suite. Abundance data were fourth-root transformed to balance the influence of common and less common taxa. Abundance dendrograms were produced using Bray-Curtis similarity plotting with single linkages. Environmental parameter (image analysis) dendrograms were plotted using Euclidean distances on normalised data to accommodate the different units used. Non-metric multidimensional scaling ordinations (nMDS) were plotted using Primer's MDS routine with two-dimensional reductions after 50 restarts. The relationship between benthic structure classes and macrofaunal abundance and composition was assessed using the ANOSIM routine while SIMPER was used to identify key taxa shaping discrete multivariate groups. For the purposes of this report it is assumed that the reader is familiar with these approaches. Some interpretive comments are provided in the appropriate results sections where specific statistics are presented.

Results

Superficial Habitat Classification

Of the 214 benthic images collected in June 2009, 197 were used in the final analysis. Classification data with some notes are listed in Appendix 1. A benthic structural type composed of small shell or coarse sand deposits over a mostly barren mudstone-like or consolidated clay bottom (flat or sculptured) was found to dominate some seafloor areas near *Te Rauone* Beach. This type of seafloor was observed in a small number of sites bordering shell-hash areas in the 2008 study. For this reason 2008 images (686 of them) were reexamined. Subsequent photo-survey results represent a synthetic analysis of 2009 and 2008 imagery.

Sampling effort in the photosurveys was skewed toward the primary shipping channel and its margins (Figure 1). The most frequently recorded seafloor structural class (described in Table 1) was current-rippled medium sand and dense algal patches or inlet-features (seagrass and seagrass margins with key infauna) depending upon the class scheme chosen (Table 2). The channel bottom appeared to be dominated by physical processes as evidenced by medium sand with current ripples and sparse algae (Figure 7). The channel slopes and margins were more frequently dominated by biological processes including bioturbation and dense algal cover. With a few exceptions, large macrofaunal burrows made by the crab *Macrophthalmus hirtipes* and the mantis shrimp *Heterosquilla tricarinata* were associated with biologically dominated habitats. Water flow features were mostly restricted to dredged shipping channel sites, but did occur in portions of tidal channels in the central sand flats. Rippled sand formed the majority of the photos at only two non-dredge sites. These were between Latham Bay and Quarantine Island (Figure 7).

Table 2. Summary of photographic analysis (2008 and 2009 surveys combined)

11 Class Scheme	% of photos	7 Class Scheme	% of photos
1 – Sand, shell, algae	7%	1 – Sand, sparse shell and algae	13%
2 – Sand, shell, algae, silt	11%	2 – Rippled sand	16%
3 – Rippled sand	18%	3 – Algal mats	20%
4 – Thick algae	17%	4 – Inlet features	24%
5 – Seagrass	8%	5 – Tube mats	8%
6 – Seagrass margin	12%	6 – Shell hash	13%
7 – Living cockle bed	5%	7 – Mudstone pavement	6%
8 – Macrofauna tubes	6%		
9 – Deep sessile	2%		
10 – Shell hash	9%		
11 – Mudstone pavement	5%		

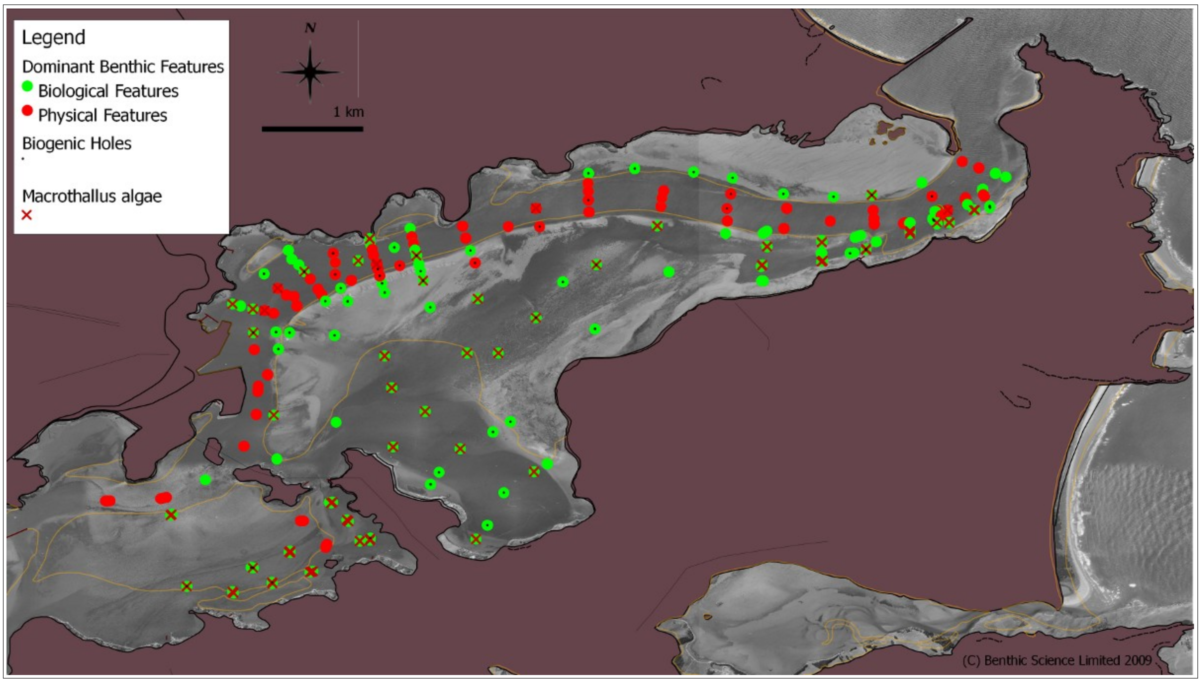

Figure 7 Dominant benthic features. Biologically dominated areas (green circles) showed recent bioturbation or dense algal cover (red crosses) and few or no obvious current features whereas physically dominated areas (red cirles) possessed clear sediment ripples and little or no algae nor apparent microphytobenthos. Black dots indicate areas where biogenic holes (made by crabs or shrimp) were observed. (Background Land Information New Zealand (LINZ) I44/J44 aerial photos from 1999-2000; non-orthorectified).

The harbour seafloor was predominantly sandy (well sorted medium-sized grains) with seagrass meadows and patches on the higest portions of the exposed sandflats intermingled with patches of algae (Figure 8). Enhanced multispectral overhead imagery differentiated the large continuous seagrass meadow opposite of Port Chalmers from algal beds but smaller seagrass patches (intertidal and subtidal) intermingled with algal mats could not be reliably identified (Figure 9). The albedo, or reflectivity, of seagrass and interference from the water surface in monochromatic images did not permit a reliable comparison of coverage through time. Benthic video feeds and direct field observations suggested that the proportion of algal cover to seagrass seemed to increase with increasing water depth until algal mats and patches dominated the margins of sandflats and deeper channels.

Whether or not a particular site was classified as an algal mat, algae formed a conspicuous and important component of almost all locations in the lower harbour. Encrusting coralline 'paint' naturally corresponded to shell and cobble deposits where flow conditions kept hard substrata exposed. Macrothallus algae dominated the shallow subtidal portions of the harbour and almost always contained filamentous epiphytic species. Small individual filamentous algal clumps were a feature of almost every subtidal site except the rippled sand areas. These algae mostly appeared to be recent growths on bivalve shells and small stones. The tunicate *Pyura pachydermatina* was recorded at a few sites restricted to physically dominated channel areas attached to large hard structures or macrothallus algal stipes. Few living cockles were directly imaged in the study, but were observed on seagrass margins and are known to occur in many other locations throughout the harbour as described in a prior report [1]. Dense algal mats were also associated with secondary channels or shallow subtidal areas on the sandflat margins and off rocky shorelines.

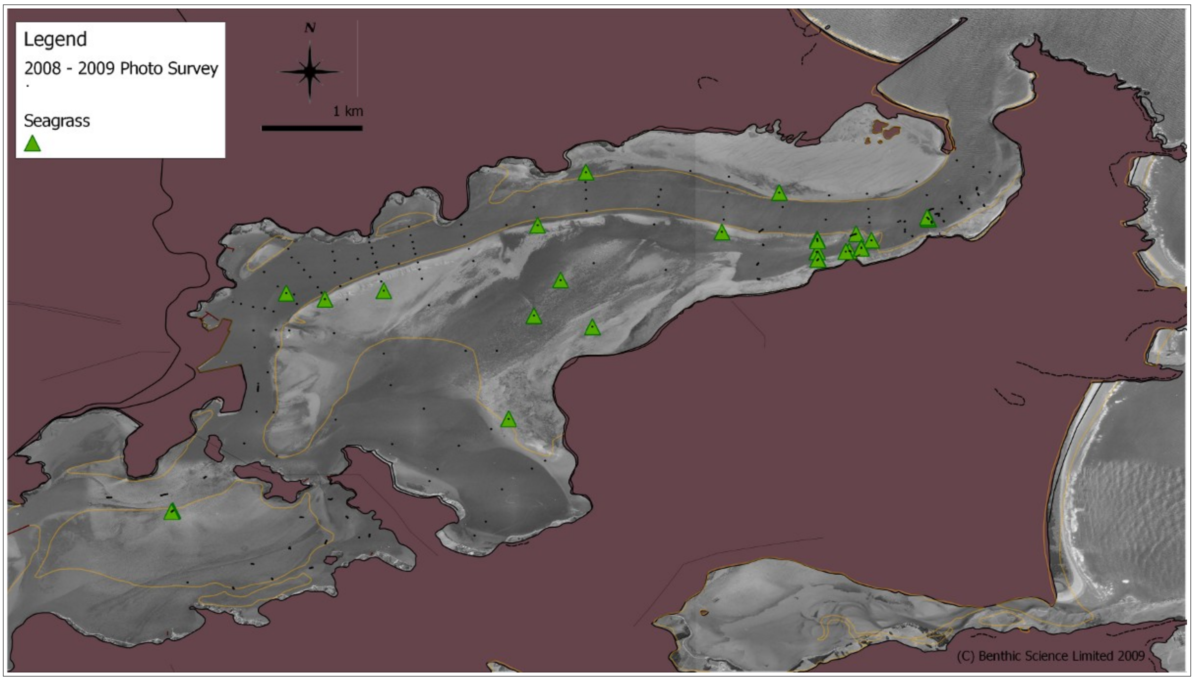

Figure 8. Seagrass (*Zostera* sp., green triangles) observed during 2008 and 2009 photo surveys.

Figure 9. Aerial photography (Land Information New Zealand I44/J44 1999-2000, top panel) and satellite mosaics (Digital Globe, 2008) highlight the sandflat features of Otago Harbour.

The green algae *Ulva* sp. (sea lettuce) was ubiquitous in the harbour (Figure 10). Sea lettuce was thick enough at times to make benthic photography impossible (Figure 11) whether it was attached to the substratum or freely drifting on sandflats and within channels. Accumulations of 0.5 to 1 m thick were observed in deeper pockets of the channel south of Quarantine Island near Sawyer's Bay. Shell deposits were a common feature of the channel bottom (Figure 10). Each of these shelly areas was dominated by coralline algae-encrusted shells (in contrast to bare cockle shells on the sand flats and near channel margins). Each deposit was comprised of a number of different shell species, but usually dominated by a single species. Some areas were dominated by *Maoricolpus roseus* shells while others were almost exclusively large *Paphies* or *Zethalia zelandica* shells. Muddy sand was encountered in sheltered areas off Deborah Bay, Portobello Bay, and near Latham Bay (Figure 12). Near the southern end of *Te Rauone* Beach the crest of the southern margin of the channel had a medium-sand berm standing 1-3 metres proud of the bottom on the southern side. Mud, with signs of heavy macrofaunal bioturbation, was present between this berm and the subtidal portion of the beach's sandy slope.

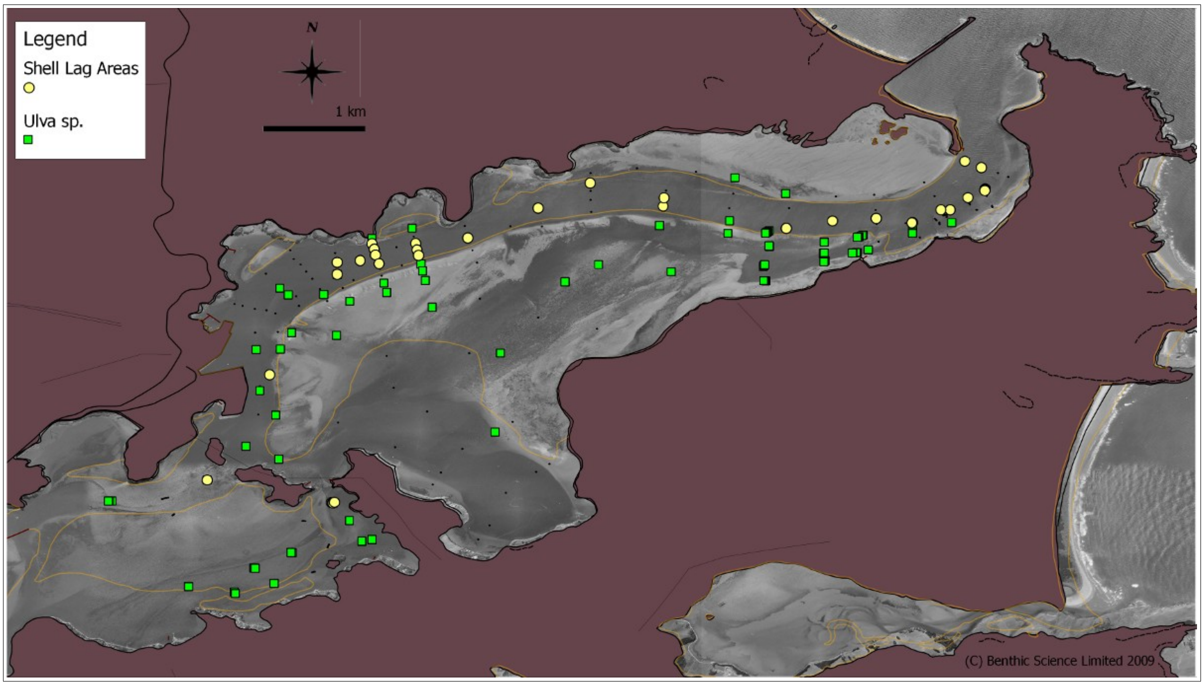

Figure 10. Presence of *Ulva* sp. (green squares) in the study area relative to coralline-algae encrusted shell deposits (yellow circles). Samples without either of these features are marked with small black dots.

Figure 11. Sea lettuce, *Ulva* sp., was common throughout the harbour, frequently in high enough densities to foul the camera system and make benthic photography difficult at many sites.

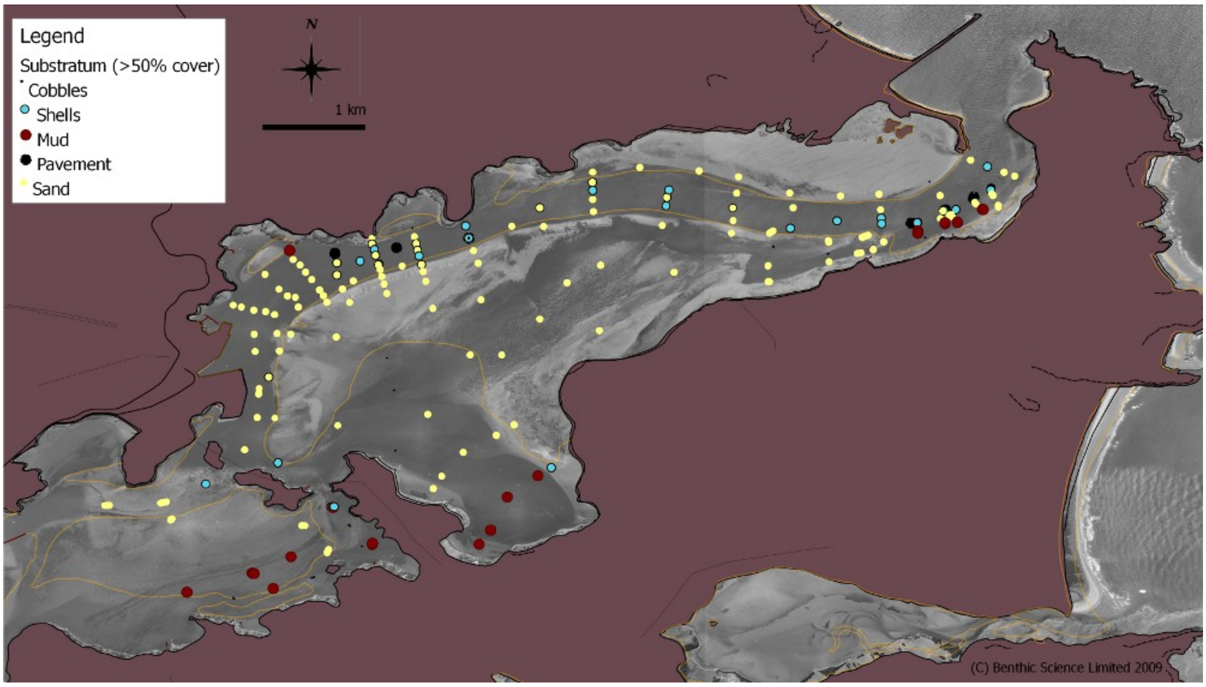

Figure 12. Primary substratum types encountered in the photosurveys (2008 and 2009).

Medium to fine sands with apparent organic debris and/or floc were an important feature of deeper, non-dredged sites in the the harbour. These areas presented dense aggregations of bioturbators and tube builders. Macrofaunal-tube dominated areas in Portobello Bay and Deborah Bay were within or bordered on deeper waters which likely helped retain the fine material observed in photos (Figure 13). Tube-mats were also observed in the muddy areas protected by the sand berm off *Te Rauone* Beach. There were scattered indications of the environmental engineering species *Callianassa filholi* (ghost shrimp) and *Abarenicola affinis* (lugworms) on the shallower margins of these areas (though more common in seagrass margins). These species are unlikely to be directly observed or sampled by the present methods (they often burrow >15 cm deep). Water motion and bioturbation limit the endurance of the seabed features they construct.

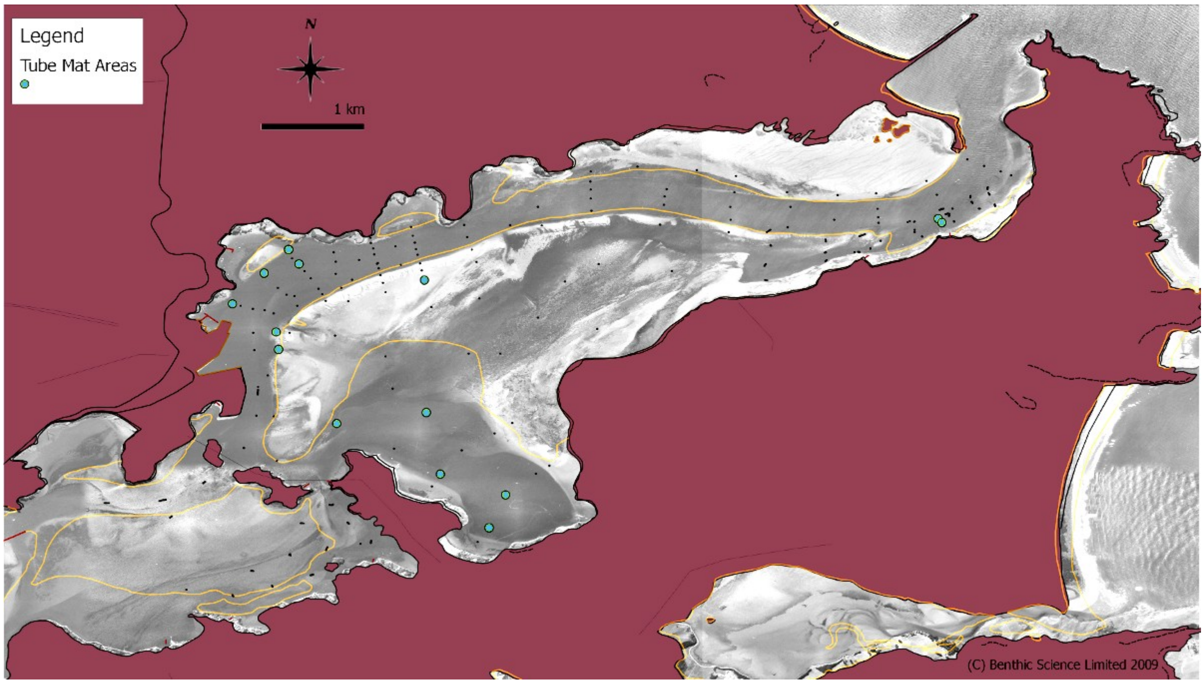

Figure 13. Benthic areas dominated by macrofaunal tube-building species in sufficient density to noticeably alter the sediment fabric.

With no *a priori* reason for estimating habitat connectivity, area estimates required rule-based (heuristic) interpolations. Benthic features were observed by live video and direct observation as the research vessel approached each study site, maneuvered, and departed. These field observations were combined with additional information such as bathymetry, presumed water flow patterns, overhead imagery, the frequency of different benthic classes observed at any one site, and local experience to interpolate benthic structures between the formal observation sites described above. It is important to note that several different benthic classes may have been observed in a given interpolation area, but only the dominant class has been represented. Similar benthic structural patterns are evident in the eleven (Figure 14) and the seven (Figure 15) benthic structure class schemes.

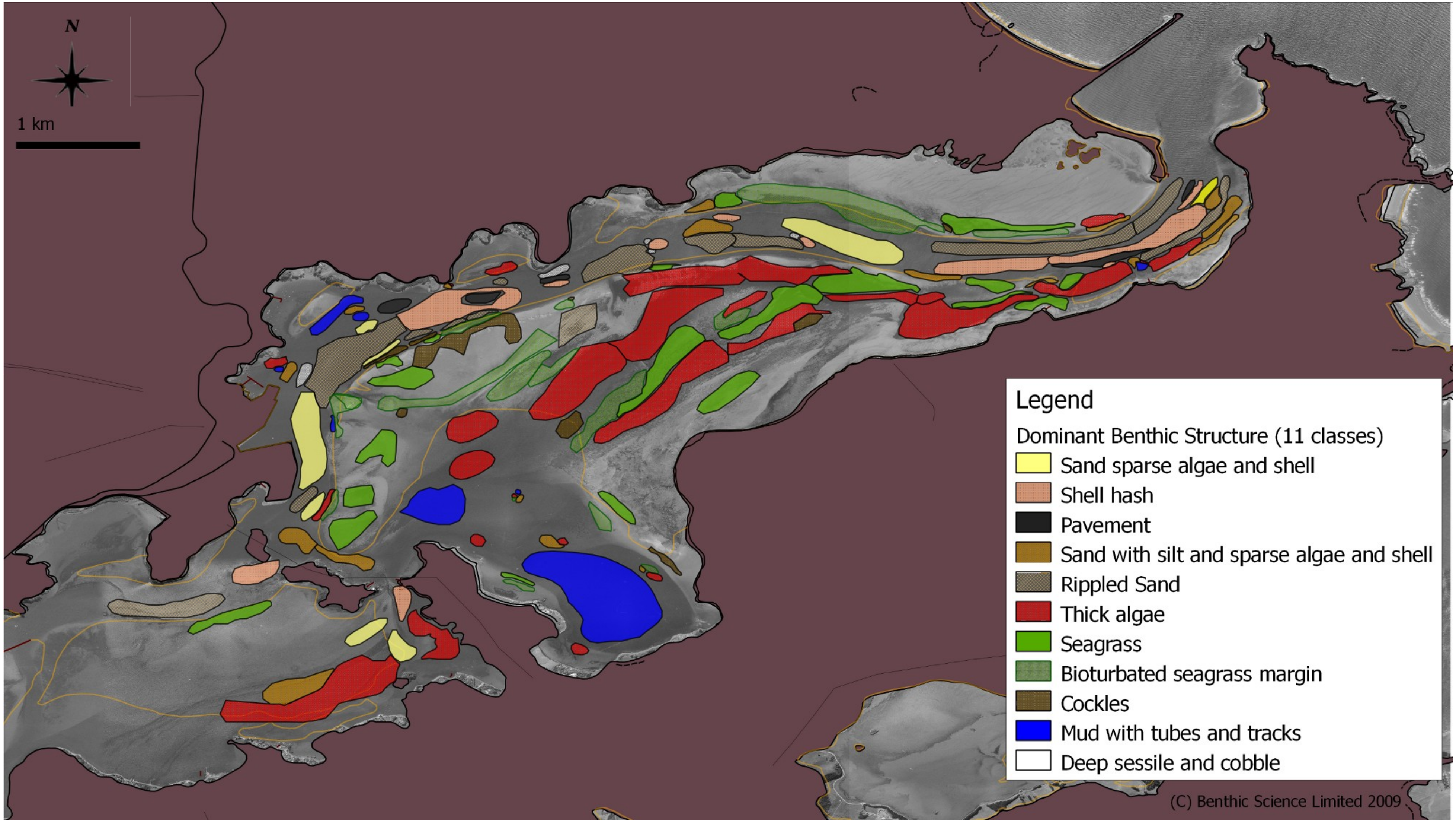

Figure 14. Interpolated dominant benthic structures (11 class scheme) from combined 2008 and 2009 photo survey data. (Background LINZ I44/J44 1999-2000 aerial imagery).

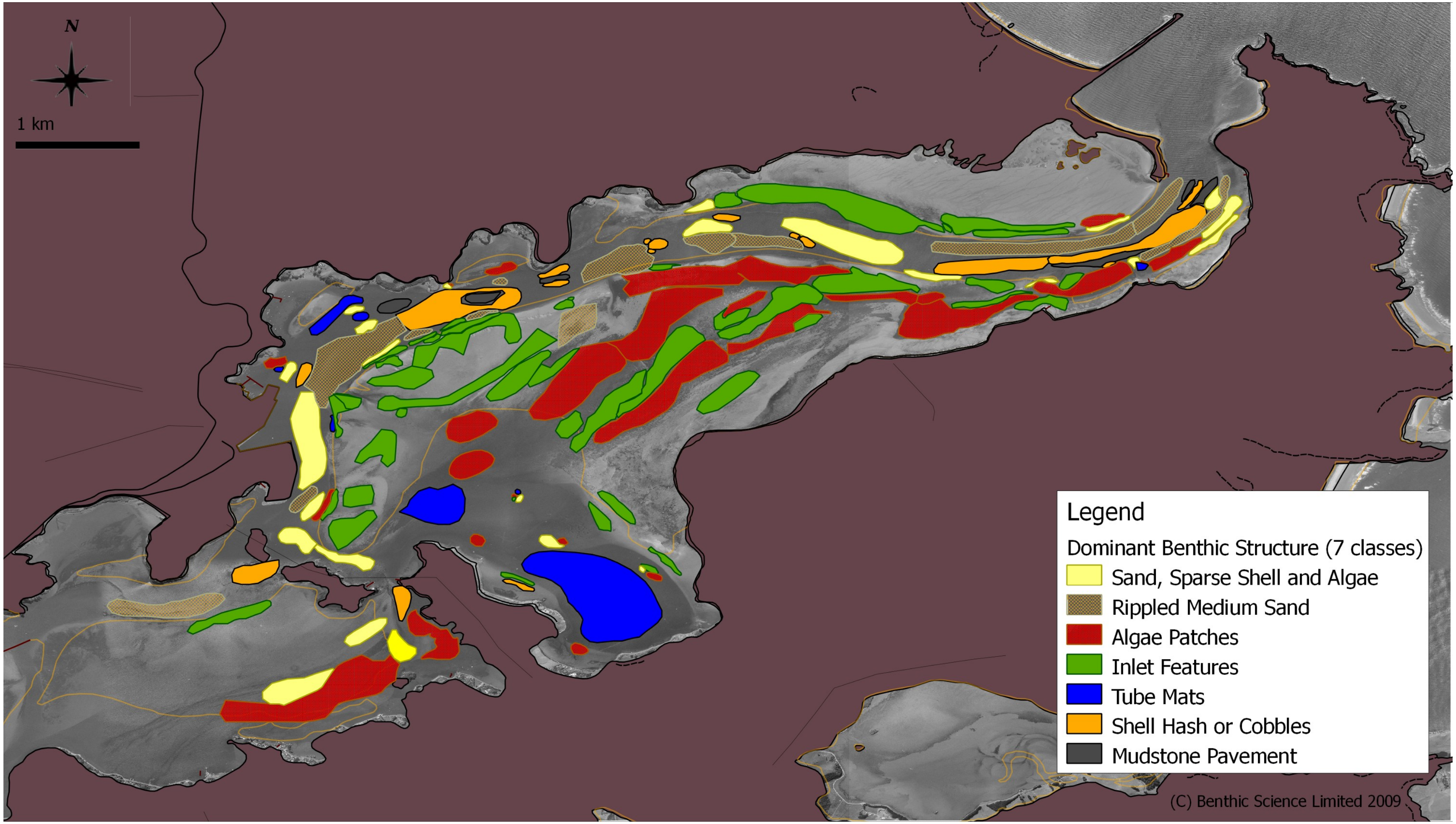

Figure 15. Interpolated dominant benthic structures (7 class scheme) from combined 2008 and 2009 photo survey data. (Background LINZ I44/J44 1999-2000 aerial imagery).

The entire lower harbour and Latham Bay study area encompasses approximately 24 km^2. Using photographic and field observation data, 40% of this area was assigned to one of the 11 benthic structural classes. Dense algal mats and inlet-featured benthic structures (seagrass and characteristic infauna such as cockles, ghost shrimp, mantis shrimp, etc.) represented the classes with the greatest areal coverage (Table 3). The patchy nature of the harbour benthos, sampling extent, and poor bathymetric detail beyond the channel resulted in about 60% (or 14 km^2) of the study area remaining unclassified. While patchiness was the norm, continuous areas of inlet features were present on the northern portion of the lower harbour channel and the shallowest (intertidal and shallow subtidal) areas of the central sandflats. Dense algal patches were consistently intermingled with seagrass, but dominated natural channels on the sandflats and sandflat margins. Classification was based on objective records from a total survey area of 79.5 m^2, being the sum of all areas photographed, which is 0.00001% of the interpolated area, however, the qualitatively observed area was actually greater by two to three orders of magnitude (video and direct observations formed part of the interpolation analysis).

Table 3. Percentage of interpolated harbour area (Figures 14 and 15) assigned to each benthic structural class (refer to Table 1 for description).

11 Class Scheme	% Area	Reduced Class	% Area
1 – Sand, shell, algae	6%	1 – Sand, sparse shell and algae	11%
2 – Sand, shell, algae, silt	5%	2 – Rippled sand	13%
3 – Rippled sand	13%	3 – Algal mats	29%
4 – Thick algae	29%	4 – Inlet features	28%
5 – Seagrass	13%	5 – Tube mats	10%
6 – Seagrass margin	11%	6 – Shell hash	8%
7 – Living cockle bed	3%	7 – Mudstone pavement	2%
8 – Macrofauna tubes	10%		
9 – Deep sessile	1%		
10 – Shell hash	8%		
11 – Mudstone pavement	2%		

Some incidental observations were recorded in the field that could not be incorporated into the analyses above. A group of at least five little blue penguins (*Eudyptula minor*) were observed diving and chasing (possibly feeding) in the seagrass area south of the cross channel (centered on 45.79990° S, 170.69455° E) on 12 June 2009 and on unrecorded field dates in 2008. One or more bull New Zealand sea lions (*Phocartcos hookeri*) were repeatedly observed at Acheron Point and the small kelp patches near the Weller's Rock and *Te Rauone* Beach walls. A sparse patch of horse mussels (*Atrina zelandica*), an uncommon species in the harbour, was observed in the muddy sands just north of Weller's rock. Unfortunately, no specimens were framed in the still photos. Dense sponge and tunicate cover was also observed during low tide on hard surfaces near the channel end of the Weller's rock groyne.

Macrofauna

A total of 7,691 individuals among 105 taxa (Appendix 2) were recovered from grab samples (9 samples from near Latham Bay and 14 from near *Te Rauone* Beach, see Figure 6) and used in the final analysis. Seven taxa were excluded from further analyses because they were chance captures of organisms the study and methods were not intended to sample (*e.g.* fish, platyhelminthes, etc.) or they couldn't be reliably quantified. For example, oysters were not included because they colonise large, stable rock surfaces, but a few small individuals were collected. Any specimens obtained with a soft-sediment grab thus represent an unlikely capture event as the grab scraped a rock or collected a recently transported animal from elsewhere. Exclusions comprised tunicates, oysters, several fish species, sponges, ostracods (seed shrimp), and damaged animals that could not be identified reliably.

It was noted that a large proportion of macrofaunal specimens were either in a reproductive state or nearly so. Several polychaete families (*e.g.* Nereidiidae, Hesionidae) exhibited 'swarming' stages, bore young or eggs (*e.g. S*yllidae, Amphipoda, and Brachyura), or had bodies laden with gametes (*e.g.* Capitellidae, Dorvilleidae, Gastropoda, and others). Some sub-adult polychaetes (Spionidae, glyceriformia, and Cirratulidae most notably) were also present. Sub-adults were identified to the highest practical resolution and enumerated, but detached juveniles (from budding families) were not.

On average, Latham Bay samples produced fewer individuals, fewer taxa, lower diversity, and marginally higher evenness than *Te Rauone* Beach samples (Table 4). Taxon richness and abundance varied directly with each other at most sites (i.e. more taxa were found when more animals were found), but there were exceptions as identified by Pielou's evenness values (J) overlain with Shannon-Weiner diversity (H') estimates (Figures 17 and 18). Diversity was lowest on the sandflat margin near the Portobello Peninsula (LB18, H'=0) where only 4 individuals were collected, and greatest near *Te Rauone* Beach (TR6, H'=2.91, Abundance = 1355 individuals). Evenness (J) ranged from 0.47 (at site TR2) to 1 (at site LB10, Abundance = 8 individuals) where a dimensionless value of 1 indicated that there were an equal number of individuals found from each taxon.

Table 4. Descriptive statistics of Latham Bay (LB) and *Te Rauone* Beach (TR) macrofauna collections. SD = Standard Deviation.

Sample	Taxa (S)	Individuals (N)	Pielou's Evenness (J')	Diversity H' (log e)
LB02	40	506	0.54	1.98
LB04	10	24	0.84	1.93
LB05	30	420	0.5	1.69
LB07	37	1034	0.69	2.49
LB10	8	8	1	2.08
LB11	3	7	0.87	0.96
LB12	5	13	0.86	1.38
LB18	1	4		0
TR01	24	91	0.87	2.78
TR02	21	387	0.47	1.43
TR05	38	443	0.79	2.87
TR06	53	1355	0.73	2.91
TR07	42	1086	0.75	2.82
TR08	17	188	0.6	1.71
TR09	21	129	0.89	2.7
TR12	36	734	0.76	2.73
TR14	20	151	0.82	2.46
TR15	10	29	0.64	1.48
TR19	24	579	0.57	1.81
TR24	33	305	0.77	2.71
TR26	4	16	0.84	1.16
TR27	13	182	0.53	1.36
LB mean	16.8	252.0	0.8	1.6
TR mean	25.4	405.4	0.7	2.2
LB SD	16.1	376.9	0.2	0.8
TR SD	13.5	406.2	0.1	0.7

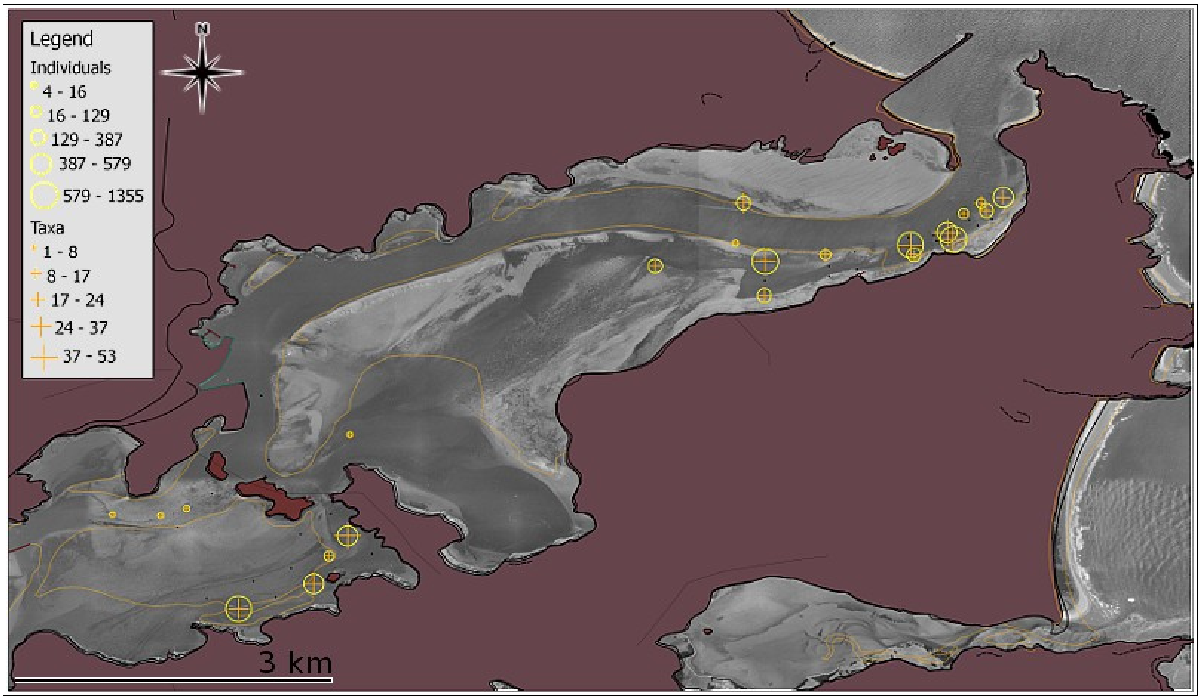

Figure 16. Macrofaunal abundance (each sample area = 0.05 m^2) classes (circles) in the study area compared to taxon richness (plus '+' signs).

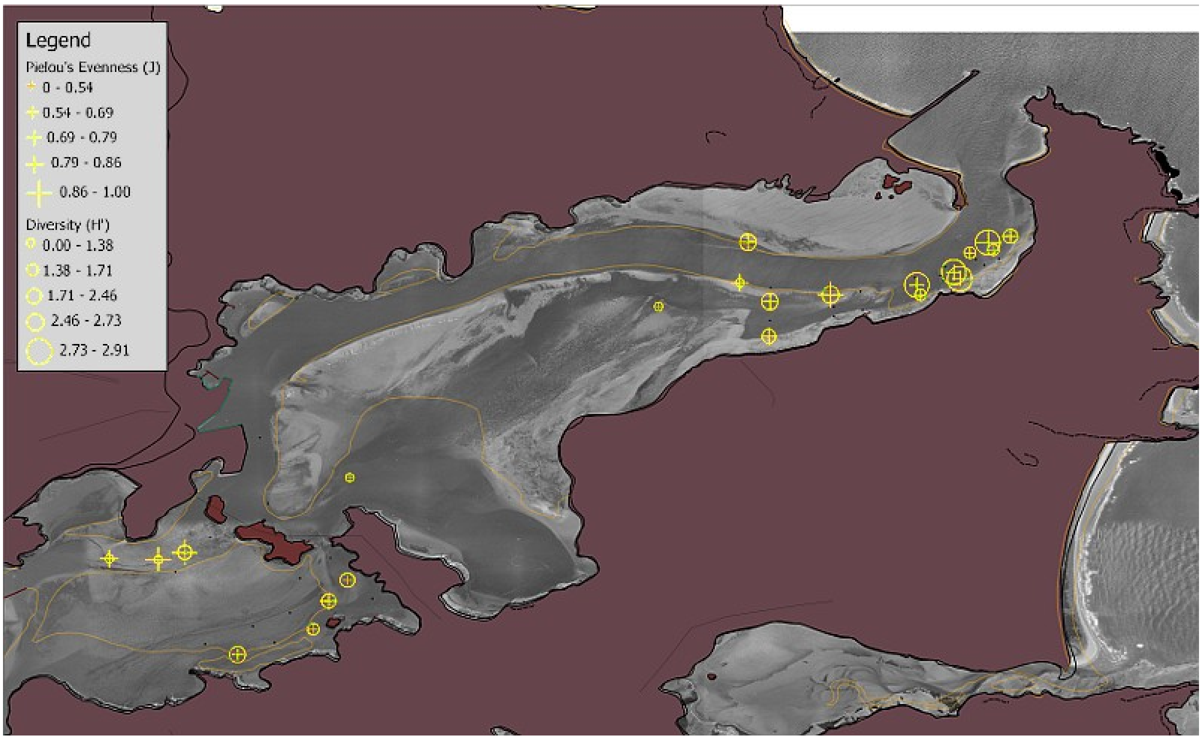

Figure 17. Pielou's Evenness classes (J) of macrofaunal samples (J, plus '+' signs) compared with Shannon-Wiener Diversity classes (H', circles).

Four of the 2008 macrofaunal sampling sites (Table 5) were resampled in 2009 to provide a rough comparison of temporal differences between studies which used the same gear, personnel, and methods. Although abundances and taxon richnesses were comparable, the number of shared taxa between years was low, thus effectively limiting further analyses which combine the two sets of data. The numerically dominant taxa among the three most abundant phyla collected in 2009 are shown in Table 6. Within each phylum, the majority of the numerically dominant taxa were the same at the TR and LB sites (2009) as were found in the entire lower harbour (2008 and 2009 data combined, Table 7).

Oligochaetes were the most numerous annelids and among the most ubiquitous taxa found. Several species are represented by this one, class-level, taxon, but they could not be identified further with available resources. Exogoninae were numerous at most sites in both years. The majority of these specimens appeared to be *Exogone sexoculata,* though at least three other taxa were readily identifiable. Sabellid polychaetes (feather duster worms) were numerous and common throughout the harbour. *Euchone* sp. specimens were enumerated separately from two other sabellid taxa, the most common of which was *Pseudobranchioma grandis*. Although fragmented specimens could not be individually identified beyond genus, the majority of *Prionospio* were either *P. aucklandica* or *P. nirripa.* Nearly all of the *Platynereis* and Nereidiidae juveniles or indeterminates were likely to be *Platynereis* cf. *kau* as identified by swarming individuals.

Tube building amphipods (Corophiidae, 'Brownback') and tanaids were the most numerous and frequently encountered crustaceans. It is unlikely that more than two tanaid taxa were recovered. Male, immature, or damaged phoxocephalid amphipods could not be readily identified further, but the majority appeared to be *Torridoharpinia hurleyi*. At least two lysianassid species make up the single family-level taxon. The isopod *Cilicaea canaliculata* was commonly found throughout the harbour as was a single diastylid cumacean taxon.

The numerically dominant taxa (Table 7) collectively account for approximately 80% of all macrofaunal individuals collected in the study (both years). The spatial distribution of each of these taxa was examined. The two taxa with the most restricted distributions were the corophiid amphipod 'Brownback' (not yet authoritatively identified) and the polychaete *Euchone* sp. (Figure 19). The limited spatial distribution was actually an artifact of temporal variability. These two taxa were not found in 2008 (though they were likely to be detected if they were there) so their spatial distribution is limited to the 2009 sample sites.

Table 5. Comparison of macrofaunal sites sampled in both March 2008 and June 2009 (Sites G31/TR27, G2/TR26, G66/TR24, and G74/LB18 from left to right)

2008 Taxa	40	11	23	12
2009 Taxa	14	4	33	2
Difference	-26	-7	10	-10
2008 Abundance	634	42	330	29
2009 Abundance	182	16	308	4
Difference	-452	-26	-22	-25
Shared Taxa	11	3	8	1

Table 6. Top-ten numerically dominant macrofaunal taxa within the top three abundant phyla recovered from 2009 grab samples. Taxa are from derived data set to allow direct comparison with 2008 values.

Taxon	**Total Individuals**	**% of Total Macrofauna**	**Present in X% of samples**
ANNELIDA ----------------------------------			
Oligochaeta	654	8.5%	55%
Exogoninae (Polychaeta, Syllidae)	376	4.9%	64%
Prionospio sp. (Polychaeta, Spionidae)	310	4.0%	64%
Sabellidae sp. (Polychaeta)	301	3.9%	27%
Euchone sp. (Polychaeta, Sabellidae)	285	3.7%	26%
Armandia maculata (Polychaeta, Opheliidae)	224	2.9%	55%
Ampharetidae (Polychaeta)	192	2.5%	50%
Prionospio aucklandica (Polychaeta, Spionidae)	190	2.5%	32%
Heteromastus filiformis (Polychaeta, Capitellidae)	111	1.2%	41%
Boccardia sp. (Polychaeta, Spionidae)	94	1.1%	27%
ARTHROPODA -----------------------------			
"Brownback" (Amphipoda, Corophidae)	693	9.0%	59.1%
Tanaidacea	390	5.0%	63.6%
Phoxocephalidae spp. (Amphipoda)	327	4.2%	86.4%
Lysianassidae (Amphipoda)	235	3.0%	45.5%
Torridoharpinia hurleyi (Amphipoda, Phoxocephalidae)	209	2.7%	63.6%
Haustoriidae (Amphipoda)	176	2.3%	50.0%
Aoridae spp. (Amphipoda)	118	1.5%	40.9%
Amphipoda indet.	69	0.9%	31.8%
Cilicaea canaliculata (Isopoda)	52	0.7%	40.9%
Diastylidae sp. (Cumacea)	46	0.6%	45.5%
MOLLUSCA ----------------------------------			
Eatoniella sp. (Gastropoda)	1015	13.10%	50.0%
Nucula hartvigiana (Bivalvia)	323	4.20%	54.5%
Mysella unidentata (Bivalvia)	162	2.10%	40.9%
Perrierina harrisonae (Bivalvia)	125	1.60%	13.6%
Turbonilla sp. (Gastropoda)	63	0.80%	50.0%
Maoricolpus roseus (Gastropoda)	36	0.50%	27.3%
Arthritica bifurca (Bivalvia)	34	0.40%	18.2%
Chiton spp. (Polyplacophora)	22	0.30%	18.2%
Gastropoda indet.	17	0.20%	9.1%
Nucula nitidula (Bivalvia)	11	0.10%	9.1%

Table 7. Top-ten numerically dominant macrofaunal taxa within the top three abundant phyla recovered from the combined set of 2008 and 2009 grab samples (resolved to highest common taxonomic resolution).

Taxon	Abundance	% of total Macrofauna	Present in X% Samples
Annelida			
Oligochaeta	3116	9.39	54
Exogoninae (Polychaeta, Syllidae)	1522	4.59	57
Heteromastus filiformis (Polychaeta, Capitellidae)	1015	3.06	44
Prionospio sp. (Polychaeta, Spionidae)	658	1.98	55
Sabellidae sp. (Polychaeta)	626	1.89	39
Terebellidae (Polychaeta)	623	1.88	40
Armandia maculata (Polychaeta, Opheliidae)	414	1.25	45
Boccardia sp. (Polychaeta, Spionidae)	316	0.95	28
Cirratulidae sp. (Polychaeta)	309	0.93	47
Euchone sp. (Polychaeta, Sabellidae)	285	0.86	8
Arthropoda			
Phoxocephalidae spp. (Amphipoda)	2043	6.16	82
Lysianassidae sp. (Amphipoda)	1511	4.55	48
Tanaidacea	1239	3.73	50
Aoridae spp. (Amphipoda)	872	2.63	60
"Brownback" (Amphipoda, Corophiidae)	693	2.09	13
Amphipoda indet.	567	1.71	65
Haustoriidae (Amphipoda)	497	1.50	32
Diastylidae sp. (Cumacea)	310	0.93	38
Cilicaea canaliculata (Isopoda)	263	0.79	40
Halicarcinus varius (Decapoda, Brachyura)	221	0.67	37
Mollusca			
Eatoniella sp. (Gastropoda)	6882	20.74	53
Perrierina harrisonae (Bivalvia)	1801	5.43	26
Nucula nitidula (Bivalvia)	1020	3.07	38
Mysella unidentata (Bivalvia)	596	1.80	42
Nucula hartvigiana (Bivalvia)	532	1.60	24
Turbonilla sp. (Gastropoda)	375	1.13	57
Micrelenchus sp. (Gastropoda)	152	0.46	24
Bivalvia "Dan1" (Bivalvia)	134	0.40	14
Chiton spp. (Polyplacophora)	131	0.39	21
Maoricolpus roseus (Gastropoda)	126	0.38	24

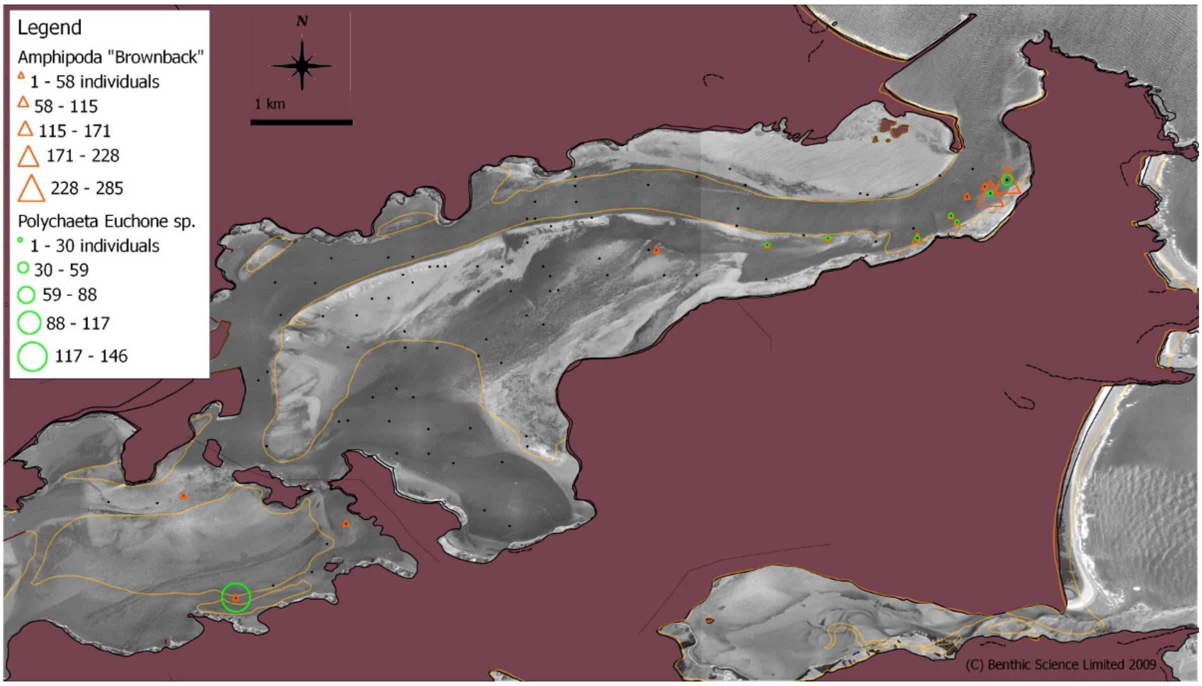

Figure 19. Distribution of the two most spatially limited, but numerically abundant macrofaunal taxa.

Brief Discussion

Benthic Structure

The purpose of the present study was to spatially augment the prior investigation[1] into the diversity and extent of superficial benthic habitat structures in Otago Harbour and identify potential benthic community boundaries prior to channel modification. The lower harbour and Latham Bay areas appeared to be a mosaic of benthic habitats which were unlikely to be successfully sampled and described using a single macrofaunal collection protocol. Soft-sediment areas were examined using ponar grabs while the hard-bottom areas were examined strictly by photo survey methods.

Results from the present study were broadly consistent with previous published accounts of the benthos of Otago Harbour (e.g.[1,2,3]) and numerous unpublished studies (notably dissertations and theses from the University of Otago). The lower Otago Harbour seafloor is a patchwork of different habitat types which may be characterised by the eleven or seven class schemes presented. This represents an increase (by one class) to the class structure outlined in 2008[1]. Observations near *Te Rauone* Beach indicated that pavement-like seabed features (the new class) extend from the Entrance Spit past Weller's Rock. A medium-grain sand bank on the southern side of the channel margin forms a retention structure for muddier sand, tube mats, and a sparse patch of horse mussel (*Atrina zelandica*). Horse mussels are uncommon in the harbour, but known from the adjacent shelf environment outside of the harbour.

Observations near Latham Bay and Sawyers Bay did not reveal any new habitat types. Deeper Latham Bay was characterised by algal patches or rippled sand bottom in areas of higher tidal flow. Shell deposits were present in the tidal narrows between Quarantine Island and the Portobello Peninsula and between Quarantine and Goat Islands.

Using interpolated values from the combined 2008/09 data, algal mats were the most spatially extensive habitat type, forming about 29% of the categorised study area. Inlet features (28%) were just as common, while rippled sand (13%), sand with sparse shell and algae (11%), tube mats (10%), shell hash (8%), and mudstone pavement (2%) were correspondingly smaller. These values are similar to the individual photograph classification

(Table 2) which was not subject to interpolation error. Photosurvey sampling effort was intentionally skewed toward the channel. Every habitat type was found adjacent to every other habitat type. The habitats were patchy on the scale of 10s to 100s of metres with the exceptions of extensive rippled sandy patches in the channel margins adjacent to Deborah Bay and the inlet-feature band on the northern side of the channel from Pulling Point to Aramoana and on the central sandflat (where it intermingles with algal patches).

Macrofauna

The dominant fauna consisted mostly of epifaunal or shallow-burrowing infaunal species. Given the large number of sediment-binding tubes present in harbour samples, surprisingly few polychaetes were found (though they were still numerous). This may be because abandoned tubes persisted in the lower harbour environment long after the original occupant was gone or the animals were too small to be efficiently captured using a 1.0 mm mesh. Among polychaetes, only a few of the taxa identified to the family level (*e.g.* Terebellidae, Cirratulidae, etc.) consisted of more than one morphospecies (identification was often limited by fragmentation), therefore the lack of distinct communities was probably a realistic reflection of the patchy (metre scale) benthic habitats in the study area as a whole.

Analyses did not reveal discrete macrofaunal communities nor restricted spatial distributions within dominant annelid, mollusc, or arthropod taxa. No single channel bottom, slope, or sandflat community was identified. Samples horizontally separated by 10s of metres differed greatly in dominant taxon composition, abundance, and taxon richness while several widely separated samples were very similar. The sites shared most species.

A number of conclusions presented in the 2008 study[1] are further supported by the present work:

1) Discrete bottom types do exist in the study area. In general, sampling density was directly related to spatial heterogeneity. The more photographs obtained in a given area, the more habitat types were found to exist within it. Every structural class was found adjacent (within 250 m) to every other class at some point. These observations suggest that the harbour's benthic habitats are patchy on the scale of 10s and 100s of metres. Two possible exceptions include the clean sandy patches in the channel

adjacent to Deborah Bay, the inlet community on the northern side of the channel from Pulling Point to Aramoana, and the extensive seagrass meadow (grading into algal patches) on the central sandflat.

2) Apparently diverse sessile invertebrate communities (including structure forming animals like sponges and tunicates) were largely restricted to deeper channel areas with extensive cobbles and boulders. An exception is the extensive sponge and tunicate cover observed on the northern side of the Weller's Rock Groyne.
3) Seagrass, cockle, *Callianassa*, and *Abarenicola*-dominated areas were restricted to lower intertidal and shallow subtidal margins of the channel. The proportion of algal cover on the sand flats (not quantified in the present work) seemed to increase with increasing water depth.
4) Clean, rippled-sand areas with few macrofaunal individuals were frequently observed in the main shipping channel, but infrequently observed in natural channel areas on sandflats. Similar features were observed in non-dredged, high-water flow areas near Latham Bay. Sediments beyond the manmade channel showed signs of extensive reworking and stabilisation by infauna.
5) Depositional areas (typified by fine sediments and extensive tube mats) formed about 10% of the study area and existed mostly outside of the channel.
6) Despite extensive sampling efforts, no evidence supporting the existence of discrete macrofaunal communities was found within the soft-sediment environment of the study area. A few environment-modifying species (such as cockles, seagrass, *Callianassa*, etc.) formed part of the classification scheme and are therefore intrinsic to the benthic structural landscape. Their presence was clearly delineated by the photographic study despite their well-understood absence in grab samples. None of the numerically dominant taxa (representing about 80% of all identified specimens) demonstrated restricted (vulnerable) distributions. With respect to these species, the lower harbour appears to consist of one spatially variable, but cohesive community.
7) Algal assemblages, dominated by brown algal assemblages, *Ulva,* and numerous filamentous rhodophytes growing on isolated shell and rubble patches among sandy substrata is the most spatially extensive habitat in the harbour and is largely restricted to the central sandflat area in waters less than 4 m deep. Additional photographic

sampling is likely to find this habitat more fractured than Figures 14 and 15 portray, most likely with inclusions of inlet-featured areas. Benthic structural classes 1 and 3 form two ends of a gradient that may be best described in any future work by continuous transect or percent algal cover methods.

The principal findings of this work suggest that though there are discrete structural habitats consisting of different substrata, overburden, and algae; the soft sediment fauna exist in overlapping patches. Unless the lower harbour system as a whole were to be disrupted, any local disturbances (on the scale of 100s of metres) are likely to be recolonised by neighbouring fauna unless a new habitat type is created. The central sandflats and less-modified portions of the harbour benthos support abundant fauna that are likely connected by several adult and larval transport pathways. Three habitat types (rippled sand, deep sessile, and mudstone pavement) were found only in the primary channel. It is likely that these habitat types, with few soft-sediment fauna, exist due to high tidal flows present in the channel. If seabed sheer forces found in these areas were to expand, then a localised drop in infaunal abundance and diversity can be expected with a concurrent expansion of the sessile fauna. Sessile epifaunal patches found in the deep channel (apx. 1% of lower harbour) and along the Weller's Rock groyne are likely to be the most sensitive to increased suspended sediment loads. Filter feeding animals like horse mussels, tunicates, and sponges provide substantial colonisation area and increase seabed complexity. These habitat types would be unlikely to exist, however, were it not for the flow conditions created by the artificial channel.

It is our opinion that bathymetery is likely to be the single most important factor in the formation and connectivity of harbour communities that influence the observed mosaic. If channel modifications do not substantially alter water flow regimes and are restricted to subtidal areas without changing the aspect or extent of intertidal areas, then the post-dredging community mosaic (barring suspended sediment loading effects – beyond the scope of this report) is likely to be very similar to the present one. If, however, modifications alter intertidal topography or depostional patterns after sediments have stabilised (post-dredging), then the affected portions of the harbour may change markedly. Detailed bathymetric data beyond the channel may provide insights into the patchy nature of the observed animal distributions.

Conclusions

Existing plans for channel modification will directly impact representatives of each habitat type found in the study. If modifications of the channel slopes and bottom will physically alter the substratum type or intertidal profile of the sandflats, local community types can be expected to change into one of the other benthic habitat classes. The expected longevity of physical alterations make engineering and geological assessments essential to the formation of biological predictions. No animals endemic to the harbour were identified.

No distinct macrofaunal assemblages (beyond engineering species integral to the structural classes) were identified. Unless water flow regimes are altered substantially in the system as a whole or new habitat types are created, localised channel modifications are unlikely to eliminate any of the identified benthic habitat classes or taxa from the lower harbour. The naturally-existing classes are present away from the channel and a large proportion of the macrofaunal taxa can be found scattered throughout the lower harbour. Only the deep sessile, shell deposit, and pavement community (not addressed by soft-sediment work) is restricted to channel areas likely to be modified. This habitat structure type is likely to be the most vulnerable to dredging operations with a slow recovery rate after direct substrate removal or after periods of increased sedimentation. This habitat probably exists as a consequence of the present channel. Soft-sediment algae are an important part of the harbour character and biomass. The algal assemblages differ structurally in the channel proceeding from Port Chalmers to the cross-channel.

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Appendix 1 - Image Analysis

Image analysis evaluations and brief notes.

·Site = study site (See methods)

·Image number = sequential photograph identifier

·Dominant = Principal forces as inferred from sediment features, B = Biological forces as evidenced by biorturbation or algae, P = physical forces evidenced by sediment ripples.

·Primary strate visible = 1 means Yes, 2 means No

·Primary substrate type = Visible substrate occupying >50% of the visual field as chosen among the following classes: muddy sand / sand / shell / cobble.

·Secondary substratum (muddy sand, sand, cobble, shell) occupying >20% of the visual field as chosen among the following classes: muddy sand / sand / shell / cobble.

·Shell condition (Recent or reLict) as determined by degree of fracture, wear, and encrusting algae

·Living cockle abundance (determined by the number of visible siphons)

·Blade algae present = 1, absent = 0

·Filamentous algae present= 1, absent = 0

·Macrothallus algae present = 1, absent = 0

·Encrusting corraline algae present = 1, absent = 0

·Seagrass (*Zostera* sp.) present = 1, absent = 0

·Sponge present = 1, absent = 0

·Macrofaunal burrows present (large features evidence of, *e.g., Macrophthalmus hirtipes*, *Macomona liliana, Callianassa filholi*, *Abarenicola affinis*, and Stomatopoda. Numerous small burrows of polychaetes, amphipods, and tanaid shrimp were not considered here)

·*Pyura pachydermatina* (Sea tulip) present = 1, absent = 0

· RecMeth = recommended method of infaunal sampling determined after review of all images from a particular site as chosen from among the following classes: D = heavy grab or dredge, P = Photographic, V = small van Veen or standard Ponar grab, C = manual core.

· CommType = principal habitat type as chosen from among 10 initial designations (see methods section, Table 1 for descriptions).

· SecCommType = habitat type (chosen from same classes as principal habitat types) observed in 2 out of 5 photos at some sites.

· Reduce = habitat type as chosen from among 6 broader categories (see mthods section, Table 1 for descriptions).

· Notes = some brief notes collected during first image review, field notes and macrofaunal observations were recorded elsewhere.

Appendix 2 - Macrofaunal Data

Data from macrofaunal samples.