A broad scale, soft sediment habitat assessment of the Hauraki Gulf

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Executive Summary

The Department of Conservation needed the soft sediment seabed habitats of the Hauraki Gulf mapped (defined here as the area south of a line extending from Waiwera due east to Colville, and excluding all estuaries and the Firth of Thames). The focus of this survey was to provide a general overview of the types of seabed habitats present and their spatial extent within the survey area, as information relevant to the potential placement of marine reserves within this area, and as a general resource inventory. This work builds upon, and compliments, previous mapping work in the Firth of Thames commissioned by the Department of Conservation (Morrison et al. 2002).

A survey of the area was undertaken from May through December 2002, using the acoustic mapping system QTC View. The survey area covered some 2,200 km^2 of seafloor, and run in two phases; the first consisting of parallel survey run-lines at 1500 m intervals for water depths less than 30 m, and 4500 m intervals for depths greater than 30 m; the second targeting special interest areas at higher spatial resolutions. QTC View has the capability to distinguish different seafloor habitat classes using acoustic returns from a scientific quality echo-sounder, using statistical methods. Ground-truthing of the acoustic data was achieved using sediment grab sampling and video imagery.

Six acoustic classes were detected with the QTC View system in the first phase, and these fell out as discrete areas within the survey area, strongly related to depth and distance offshore. Visual examination of sediment grab samples indicated a range of sediment substrates, but all were heavily dominated by muds. Second phase sampling found smaller areas of harder soft sediments, including shell-armoured bottoms associated with stronger current flows. Significant additional unexplained variability was present in the phase 1 QTC View plots, but could not be teased out in a statistically significant manner using the diagnostic tools available. This suggests that additional habitat /acoustic types were present within the sixth QTC acoustic class.

Epifaunal assemblages were very sparse, and patchily distributed across the sixty-one ground-truth sites, with an overall low diversity of epifaunal organisms. Epifauna was more common in the second phase areas of Motuihe and Ponui Channels, and appeared to be associated with areas of stronger current flow.

Three sediment samples were collected from the grab samples at each of the ground-truth sites, and have been archived; grain size analysis of these could be undertaken in the future if required, and might provide very valuable insights into the sediment differences between the various mud acoustic classes. In addition, the remaining sediment material from each site was sieved (1 mm mesh size), and the infauna preserved. The analyses of these samples were not part of the contract reported upon here, but some of the samples are being sorted and will be reported on as part of a separate DOC contract.

Data from a series of Hauraki Gulf fisheries trawl surveys undertaken from 1982-2000 were extracted from a Ministry of Fisheries database, and summarized for this report. Common inshore coastal fish species dominated, including snapper *(Pagrus auratus),* jack mackerel *(Trachurus novaezelandiae),* John dory *(Zeus faber),* red gurnard *(Chelidonichthys kumu),* and sand flounder *(Rhombosolea plebia).* Many of these species were present in significant numbers as juveniles. Results from these trawl surveys indicated that in general shallower areas of the Hauraki Gulf supported higher abundances of fish. In particular, snapper and trevally appeared to have an affinity for acoustic class 6.

Habitat change over time from sedimentation, urbanization, fishing and other human activities in the Hauraki Gulf are unknown, but may have been historically very significant. The large green-lipped mussel beds once common in the inner Hauraki Gulf, fished out by the mid 1960's, have clearly not recovered in the last 40 years. The results of this survey work indicate that the Hauraki Gulf now consists of broad areas of similar habitat, with relatively low levels of epifauna. Small areas of higher habitat heterogeneity are found around higher current areas, such as the Motuihe and Waikehe/Ponui channels.

The data presented in this report provides baseline habitat information, which will assist in planning for marine reserves or other conservation/survey work within the survey area. The data are stored as ArcView digital coverages, which will allow other spatial data sets to be overlaid as they become available, providing for the integration of diverse data sets.

1. Introduction

Marine reserves are important resource management tools for marine environments. They provide a range of potential benefits, including the protection of habitats and associated species sensitive to disturbance, providing places where the public can view nature in abundance, where scientific research can be carried out in more "natural" settings, and may provide a means of providing insurance for marine fisheries management.

However, in order to develop a more systematic means of protecting representative areas of coastline and associated benthic habitats, resource/habitat inventories are required to provide management agencies with information on the natural resources present. This represents a challenge, in terms of the often large spatial areas that need to be covered, versus the costs of survey work. More traditional methods such as diver surveys and grab sampling very quickly become less effective with increasing spatial scales and with increasing water depth. Newer and more innovative approaches are needed to address this issue.

Remote sensing tools provide a means of cost effectively surveying large marine areas when used in collaboration with more traditional sampling tools. In marine environments, light orientated remote sensing tools (aerial photography, airborne spectral sensors) quickly lose power with increasing water depth, due to turbidity and reduced light penetration. Acoustic tools do not suffer from this problem, offering a powerful means of mapping seabed habitats of inshore and coastal waters. Side scan sonar and swathe bathymetry have been available for several decades and offer very effective tools for mapping features such as reefs and other large geophysical structures. However, newer point based acoustic systems are now also commercially available (such as QTC View), that can offer better resolution of different classes of soft sediment habitats that are more subtle, and with lower operating and/or analysis costs. Ideally both approaches should be used in tandem, but cost issues do not always make this a practical and viable option. Each technique offers different strengths and data returns.

In this project, the Department of Conservation (Science and Research Unit) wished to gain information on the soft sediment seafloor habitats within the Hauraki Gulf, to provide a general seafloor habitat overview of the Gulf, and build upon and expand previous related work in the Firth of Thames.

A two-phase survey design was implemented to gain the best data returns, utilizing QTC View. The overall survey resolution (the spacing of acoustic survey run-lines) was dictated by the number of survey days able to be supported; this set a resolution of 1500 m between run-lines for the first phase of the survey. Such a run-line spacing is sufficient to identify broad habitat zones at the scale of 1000s of metres, however, it does not support finer scale detailed habitat mapping (especially of mosiac forming habitats). The second phase of mapping targeted areas identified as being of special interest from the first phase results; these being a proposed marine reserve site (Te Makutu), and areas of high/low acoustic class variability identified in the first phase (low - Whangaparaoa block, Te Matuku; high - Motuihe, Pouni Channels). Thus this report provides a picture of the main habitats and their spatial extent within the survey area at a relatively broad spatial scale, with higher resolution of smaller survey blocks embedded within this.

1.1. Background on the Hauraki Gulf

The Hauraki Gulf is a large coastal embayment, supporting a range of marine habitats and associated species. Pioneering work by A.W.B Powell in the 1930's around the Waitemata Harbour, Inner Gulf, Whangaparoa and Omaha Bay, identified a range of distinct benthic animal assemblages (Powell, 1936). Including the Waitemata Harbour, most of the surveyed area was covered by a heart urchin *(Echinocardium austale)* dominated assemblage, which changed in higher current areas (e.g. Motuihe and Ponui Channels) to assemblages dominated by other species such as turret shells *(Maoricolpus rosea),* morning sunset shells *(Tawera spissa),* and nutshells *(Notocorbula zealandia).* More recent work by Hayward et al. (1997, 1999), concentrating on Waitemata Harbour and Rangitoto Channel, found substantial benthic assemblage shifts since Powell's work, including the presence of a large number of invasive invertebrate species. Tricklebank et al. 2001 conducted a large-scale survey for one particularly intrusive invasive (nominally) species, a *Chaetopterus* tube worm, finding it to be widespread along the north-eastern coast, from Bream Head through to the Mercury Islands.

The Hauraki Gulf and Firth of Thames also support important harvestable bivalve resources, including historically extensive green-lipped mussel beds (Reid 1968, Greenway 1969). These beds formed a spatially significant benthic habitat, and were heavily fished using dredges from the 1920s to the 1960s. Reid (1968) listed the main areas as Rangitoto Channel, Islington Bay, Tamaki Strait, Ponui Island, Ponui-Thames, Orere Point-New Brighton, and New Brighton to Thames. Mussel beds occurred along the entire Coromandel coast, from Te Puru to Colville. Throughout the 40 years of the fishery, 2-4 vessels operated full-time, with some additional casual boats, landing a high of 40,900 sacks of mussels in 1961 (estimated at 15 million mussels). However, by 1966 the fishery had collapsed (Greenway 1969). Beds were serially depleted; as the populations around Coromandel and the eastern Firth shoreline declined, effort turned to the southern and western areas, then to Ponui Island, and finally to random searching over the whole area (Greenway 1969). The prevailing theory at the time seems to have been that the populations were unsustainably fished down, but at the same time dredging had removed settlement surfaces for newly recruiting mussels, which were extracted as part of the mussel/byssus matrix. It was thought that a spatial refuge remained for populations on rocky reef areas, but that these were also were coming under threat from increasing recreational harvesting (Greenway 1969).

Commercial scallop assessments have quantified scallop populations off Colville, and the eastern side of Waikehe Island (Hooks Bay area) (Cryer & Parkinson 1999), along with some detailed work on incidental impacts of scallop dredging on undersize scallops (Colville, Morrison 1995). Intertidal shellfish populations (cockles, pipi) are now perceived to be under intensive pressure in the Hauraki Gulf, an ongoing Ministry of Fisheries monitoring programme surveys a number of Auckland beaches (Morrison & Brown 1999), with environmental impacts being increasingly acknowledged as being as, if not more, important as actual harvesting.

Published knowledge of Hauraki Gulf soft sediment fish assemblages is largely limited to trawl survey data from ongoing surveys for 1+ snapper carried out across the general Hauraki Gulf every 3-4 years (e.g. Morrison & Francis 1999, Morrison *et al.* 2002a), and previous trawl sampling work pursuing various investigations on the snapper fishery (Paul 1976). Kendrick & Francis (2002) used these trawl series (1964-1997), to look for consistent fish assemblages, finding four assemblages; sediment type was found to be an important factor for many fish species.

Extensive fisheries modeling has been carried out for the Hauraki Gulf (part of SNA1) snapper stock, including both the commercial and recreational sectors (Annala *et al.* 2000). The Hauraki Gulf is also a productive inshore fishery, both commercially and recreationally, especially for snapper *(Pagrus auratus).* Thrush *et al.* (1998) compared benthic species assemblages inside and outside trawl fishing areas and reported significant variation in benthic communities that related to commercial fishing impacts.

2. Methods

2.1. Data collection tools

Two phases of acoustic data collection were undertaken using QTC View.

The acoustic mapping system QTC View uses a standard scientific echo sounder (single beam), and works on the basis of statistically clustering the characteristics of individual acoustic ping stacks (usually 5) into habitat classes, based on clustering software algorithms that attempt to minimise the amount of variation between acoustic clusters (=groups of ping stacks). Each acoustic ping stack from a scientific quality echosounder is measured for returning voltage, and a series of algorithms used to produce 166 individual factors. This data is run through a Principal Components Analysis (PCA), compressing the information present in the data down to three principal components (Q1, Q2, and Q3). These components may form separate clusters in three dimensional (3D) space, representing groupings of ping stacks that are more acoustically similar to each other within clusters, than to pings in other clusters - each of these clusters may represent a particular bottom type.

In QTC IMPACT, (the processing software of QTC View) the initial PCA data cloud (representing the first three PCA dimensions, called "Q" values) is split into two clusters, using algorithms that work on minimising variability within clusters while maximising variation between clusters. Diagnostics are provided within the software that allow the user to assess whether each further split is warranted, and whether each additional split significantly improves the overall explanation of the statistical variance within the data cloud. At some point, further splits become unwarranted, and the final number of splits is therefore determined.

Once the final number of splits has been determined, each ping is compared in PCA space to the centroid of the cluster to which it has been assigned, and assigned a confidence value ranging from 0-100, which is a measure of how confident the system is that the classification is correct. For example, a high confidence value would indicate a ping that fell well inside the 3D space of a particular habitat class, while a low value might represent a ping that fell equidistant between two classes, or in an area of 3D space that was well away from the centroid of its assigned class. Each cluster of points is assumed to represent a habitat type. Independent ground-truthing information (e.g. from video cameras or sediment grab sampling) is required to assign habitat identities to each of the acoustic clusters.

Full details of the operation of the QTC IMPACT system are provided in the user manuals, which can be provided upon request.

The data generated and manipulated by QTC IMPACT can be exported into a GIS post-processing environment, where it is converted into a habitat polygon and overlaid onto site maps.

2.2. Survey data collection

2.2.1. Phase 1

Survey run-lines for QTC View were placed at 1500 m intervals in a west-east orientation (Figure 1). The spacing of the run-lines was set by the number of survey days available, divided by the total spatial area to be sampled. Boat speed averaged approximately 3 metres per second during the survey runlines. A differential Global Positioning System was used to ensure high spatial accuracy in navigation, and recording of the spatial data.

Two data collection systems were run simultaneously during the survey. QTC View was used to collect bottom habitat classification data, while HYDRO™ (Trimble Ltd) was used to record spatial positioning information and depth measurements.

Two different survey vessels were used; the University of Auckland's research vessel '*Hawere*', and the Department of Conservations vessel '*Hauturu*''.

2.2.2 Phase 2

Preliminary results from the first phase were discussed with DOC's S&R unit, and phase 2 sites chosen to cover smaller seafloor blocks that represented both high and low habitat acoustic variability areas. These sites were; low acoustic variability, proposed Te Matuku marine reserve (Waikehe Island) (7 km^2), North of Whangaparoa Peninsula (3 km^2); high acoustic variability, southern Motuihe Island (9 km^2) and northern Ponui channel (9 km^2) (Figure 1).

2.3. Ground-truth data collection

2.3.1. Phase 1

Twenty-six phase one ground-truth stations were selected from viewing provisional QTC View ping stack classifications, and placed so stations fell within patches of 'pure' acoustic classes, i.e. patches of mixed classes, or areas of acoustic transition, were avoided where possible.

Both video footage and sediment grab samples were collected from each station. Video footage was collected using a low-light underwater camera, suspended on a sledge held just above the seafloor. The survey vessel was allowed to drift with prevailing wind and tidal currents for a period of ~10 minutes, or the engines used to hold the vessel on station / move it slowly, depending on current speeds. Video footage usually covered 100-200 m of seafloor. The sledge was not towed due to potential problems over soft substrates of stirring up of soft sediments obscuring the imagery. Footage from each station was viewed and assigned a habitat description based on the dominant habitat elements present (e.g. muds, sands, shell gravels). Notes were also made of any conspicuous epifauna in the video images, including green-lipped and horse mussels, scallops, sponges, and ascidians.

A Smith-McIntyre gab sampler was used to collect three sediment samples from each of the ground-truth stations. Each sample was visually assessed for primary substrate type (muds, sands, shells, rocks), and for secondary cover such as larger dead shell, sponges, and rubble. A sediment scraping ~3 cm deep was taken from the center of each of the cores, and archived for potential later sediment analysis (a 200 kHz sounder can be expected to penetrate 2 to 4 cm into the soft substrates, depending on hardness). The remaining sediments were run through a sieve of 1 mm mesh size, and preserved in formalin for later analysis of the infauna.

2.3.2. Phase 2

Initial QTC clustering was undertaken individually on each of the phase 2 sites, and a minimum of two ground-truth stations assigned to each of the acoustic classes identified. Stations were assigned as per phase l, in areas of 'pure' classes, avoiding areas of acoustic transition or high variability. A further 35 phase 2 ground-truth stations were sampled.

2.4 Processing and analysis of GIS data

QTC and HYDRO raw data files were groomed for obvious outliers based on depth. The HYDRO depth data was corrected to chart datum to adjust for tidal variations. QTC data consisted of a series of points with a spatial co-ordinate position, a depth value, the three principal components (Q1, Q2, Q3), an associated habitat class and the class confidence value at that point. Files were imported into Arc/Info by the GENERATE option. Attributes were also imported into Arc TABLES and joined with the imported point coverage. Data spatial transformations were done as required (Latitude/Longitude to NZMG).

Each of the 3 principal component values was used to generate a separate surface using an interpolation method (either KRIGING or Spline curve fitting). The best method depended on sampling and interpolation intervals and required a comparison of results from both techniques.

After construction of the 2-D surfaces (also known as grids) for each principal component, the three surfaces were combined into a "stack", and a supervised classification procedure applied. Classifications were obtained using the maximum likelihood method available with ARCINFO. Various tests available within the procedure were used to optimise classification parameters to obtain the best classifications possible. The resulting classes on the 2-D grids (at a 5 m resolution) were converted into polygons, representing the spatial extent of the different habitat classes.

ARCVIEW was used to produce plots of track lines and ground-truth sites, for export into other GIS databases.

2.5 Collation of pre-existing data

2.5.1. Ministry of Fisheries 'trawl' database

Fisheries trawl surveys have been conducted in New Zealand's coastal waters since the 1960's, to describe fish species and assemblage patterns, and to monitor fish stocks for changes in their abundance (biomass) and population size frequency compositions. One of the longest and most intensive time series is for the Hauraki Gulf/Firth of Thames, which supports the main commercial and recreational snapper stock. Trawl surveys have been run since 1982, using the R.V. Kaharoa (a 28 m stern trawler), to estimate the relative number of 1+ snapper (aged between 1 and 2 years) present in the Gulf with respect to sea surface temperatures. A strong correlation exists between the average sea surface temperature in February of the preceding summer, and the number of 1+ snapper the following summer (until the most recent survey in 2000, the correlation coefficient was 0.96). In brief, the method is to tow a high opening bottom trawl net for distances of 0.7-1.0 nautical mile (1296-1852 m), at a speed of 3-3.5 knots. The minimum water depth for sampling is nominally 10 m. The cod-end mesh size is 40 mm, and a range of fish species are caught, although larger fish (such as snapper over 35 cm) are able to out-swim the sampling gears, and many probably escape. Current survey target species in the Hauraki Gulf are 1+ snapper, and secondarily red gurnard and John dory (Morrison *et al*, 2002a).

For the purposes of this report, all trawl stations completed since 1982 that fell within the Hauraki Gulf survey area were extracted from the '*trawl*' database, and catches standardised to numbers of fish per square km of seafloor. This was calculated by taking the number of fish caught per tow, and correcting for the distance towed, and the width of the trawl doors (these hold the net open, and 'herd' fish between them into the path of the oncoming net). Each trawl survey was undertaken according to a pre-designed survey stratification that maximized the statistical efficiency of the shots within a survey, so that shots within any specific survey stratum would in theory be as similar as possible to each other in their target species catch rates. Stations were randomly allocated within strata (see Morrison *et al.* 2002 for most recent stratification).

For this report, we assume that stations were randomly located throughout the current Hauraki Gulf survey area (where water depth was greater than 10 m) and that summing across station catches is a fair representation of the fish assemblages found in the area. We also use data across multiple years (surveys), which is likely to have smoothed out the potentially significant temporal variation present. For instance, 1+ snapper can vary over an order of magnitude in their abundance between different years. The Hauraki Gulf snapper population has also been rebuilding since being heavily exploited in earlier decades, so there have been increases in overall abundance of the general stock.

The findings presented here therefore are a 'general' snapshot of the fish assemblages of the Hauraki Gulf able to be sampled by fisheries research trawl. For display purposes, the fish data is presented as bubble plots, split into density bins; these bins are the same as those presented in the previous Firth of Thames report (Morrison *et al.* 2002b)

2.5.2. Historical mussel information

Substantial green-lipped mussel fisheries used to operate in the Hauraki Gulf and the Firth of Thames. These fisheries, and their eventual sharp decline and collapse, were summarised in a fisheries technical report (Reid 1968), and a scientific paper (Greenway, 1969). Included in these works were maps of mussel distributions from the 1960s and earlier. These two maps were scanned, and overlain as spatial coverages on the current survey information. Ground-control points were used to correct the image to real-world coordinates, although some inconsistencies with the coastline data remain (due to different resolutions and scales used).

3. Results

3.1 Bathymetric mapping and visual sediment analysis

3.1.1. Bathymetry

Overall water depths in the survey area ranged from two m above chart datum (intertidal flats) out to sub-tidal water depths of 46 m below chart datum. Bathmetry was gently sloping in open areas - north and south of Whangaparoa Peninsula, north of Waiheke Island, the Tamaki Strait and west of Colville Harbour - with steeper and more complex contours between islands (Rangitoto, Motuihe, Waiheke, Ponui) (Figure 2).

3.1.2. Ground-truth data

Sixty-one sites were sampled by grab and video sampling (Phase 1, 26, Phase 2, 35; Table 1, Figure 3). In Phase 1, six general benthic habitat classes were identified, all six were various classes of mud. Visually, and textually through the grab samples, it was not possible to distinguish major differences between these classes of mud, apart from the level of mud softness. Sands were largely absent, and in general shell cover was quite low, in both the grab and video samples.

Secondary biological habitat elements included starfish, and hermit crab tracks at some stations, but epifauna was very sparse overall.

In the second phase (Figure 1), a wider range of substrates were encountered. Of the two nominally low acoustic variability sites (identified in Phase 1), the Whangaparoa site showed little variability, being composed of soft muds with little epifauna, while Te Matuku had slightly more variability, with different mud classes, with some changes in shell presence. Te Matuku had cushion stars present at several sites, along with numerous sloped burrows (probably a crustacean species - a number of large shrimps were taken in the grab samples). One station had heavier shell cover, with associated yellow sponges, and wandering anemones.

The two higher acoustic variability sites (as identified in Phase 1) also contained more habitat variability. Motuihe had habitats ranging from muds and sands, through to cobbles and shell armoured seafloor, with at times abundant epifaunal species such as turret shells (Maoriculpus rosea), rhodoliths, hydroids, cushion stars, horse mussels and yellow finger sponges. Ponui had a similar range of habitats, though it was more dominated by muds. Epifauna included horse mussels, scallops, and encrusting sponges, although overall these seemed less common than at Motuihe. The more armoured bottom types tended to have more abundant epifaunal assemblages, but the relative interplay between the degree of habitat complexity, and current energies, in driving epifaunal dynamics was unclear

Overall, the epifauna in the Hauraki Gulf was sparse, and occurred at only higher densities at only a small subset of stations.

3.2. QTC View Data

The Phase 1 Q values formed a broad "V" in three-dimensional space (Figure 5), with a very sharp inflexion point at the apex of the V. It should be noted that some 130,000 acoustic returns contributed to this record, so data obscuring in the plot (many points overlying each other) is substantial. Splitting of the PCA cloud using the algorithms contained within the QTC IMPACT software resulted in an optimal split of 6 acoustic classes. Substantial additional acoustic variability was apparent in class 6, but this could not be teased out statistically within the QTC IMPACT software environment

These six acoustic classes fell out as discrete areas within the survey area, strongly related to depth and distance offshore (Table 2). Visual examination of sediment grab samples indicated a range of sediment substrates heavily dominated by muds. Apart from 'softness', it was unclear how these muds varied in their characteristics. Sediment grain size data is not currently available, but if completed may provide very valuable insight into what additional factors may be driving differences between the six acoustic classes.

Second phase sampling found smaller areas of harder soft sediments, including shell armoured bottom associated with stronger current flows. The apparent level of acoustic diversity was well matched between the phase 1 and 2 sampling, with Motuihe and Ponui being more diverse in both phases. Whangaparaoa and Te Matuku were less diverse; both fell into only one habitat class (respectively) in phase 1, while in phase 2 Whangaparaoa could equally have been left as 1 acoustic class, as split into 2. Te Matuku also did not split out as well during the QTC analysis and subsequent GIS operations, suggesting that its acoustic classes were also less well classified than the Motuihe and Ponui data sets.

3.3 Fish trawl data series

Data extracted from the Ministry of Fisheries '*trawl*' database showed that the fish fauna of the soft sediments areas was dominated by relatively few species; in order of overall abundance the top six were were snapper, jack mackerel (*T. novaezealandiae*), John dory, red gurnard, sand flounder, and trevally (Table 3). A further 48 fish species were caught at lower abundances. It should be noted that larger fish are probably capable of outswimming the trawl gear (towed at 3-3.5 knots), and that for more pelagic species such as jack mackerels and kahawai, it is not known how these species are distributed through the water-column (the opening height of the net at its highest point is generally around 5-6 m from the seafloor).

Snapper size frequencies showed several size modes, at 9, 15, and 25 cm, probably representing 0+, 1+ and older fish respectively (Figure 6a). The large numbers of juvenile snapper caught (less than 25 cm) demonstrates the value of the Hauraki Gulf as a nursery area for this species. This species dominated the catches of fish for all survey years. Snapper were distributed throughout the survey area (Figure 7), but were concentrated in shallower areas, especially north of Whangaparaoa, and off northwest Waiheke Island. There appeared to be some affinity for acoustic class 6.

Jack mackerel (*T. novaezealandiae*) was the next most commonly caught species, with a modal size distribution centered around 18 cm (Figure 6a). Jack mackerel were similarly distributed to snapper, but with higher abundances in deeper areas also (Figure 8). John dory size frequencies were dominated by a juvenile mode at 19 cm (Figure 6a), with abundances higher in shallow areas, although few were caught in Tamaki Strait (Figure 9). Red gurnard were caught across a range of sizes, from 6-44 cm, representing both juveniles and adults (Figure 6a). Abundances of red gurnard were widespread but patchy throughout the survey area, with low abundances south of Whangaparoa, and in the Tamaki Strait (Figure 10).

Sand flounders were generally present at sizes of 15 cm or greater, with a mode at 25-29 cm (Figure 6a), consistent with smaller fish using shallower depth waters as nursery grounds. Sand flounder were most common north of Whangapaora, and north of Waiheke Island (Figure 11). Trevally were present across a wide size range (Figure 6a), and were very spatially aggregated, with concentrations north of Whangaparoa, between Rangitoto and Waiheke Islands, and off northern central Waiheke Island (Figure 12). As with snapper, there appeared to be some affinity for acoustic class 6.

Rig were present as two main size cohorts, at 40-60 cm, and 60-80 cm. (Figure 6b), and occurred throughout the survey extent sporadically, with highest catches being made between Rangitoto and Waiheke Islands (Figure 13). Barracouda were present as two very distinct size modes, at 14 and 34 cm (Figure 6b). They were uncommon in trawl shots, and occurred at only a few stations (Figure 14). Finally, kahawai were sampled as three size cohorts, at 20 (dominant), 28, and 44 cm (Figure 6b). Larger kahawai were likely to have out-swum the trawl gear. Kahawai were seldom caught, although numbers were sampled in the Tamaki Strait (Figure 15).

3.4 General comments on the biology and ecology of the area

The soft sediments of the survey area were composed almost entirely of various classes of mud. While the QTC system identified six different acoustic mud classes, it was not apparent from visual inspection what was responsible for determining this classification, apart from 'softness'. Sandy habitats were rare; while these occur in the Hauraki Gulf, they tend to be associated with moderately exposed, very shallow areas adjacent to beaches; this survey largely excluded such areas.

Smaller areas containing more diverse habitats and associated epifauna were found in the Motuihe and Ponui Channels, which experience strong current flows. The once abundant green-lipped mussel beds in the inner Hauraki Gulf, overfished in the mid 1960s (Figure 16), have not returned. Despite large amounts of dead sub-surface shells being encountered during sieving of the grab samples, few other large live bivalves were present, apart from the occasional patches of horse mussels or scallops. The grab sample benthos has been preserved, allowing for future analysis to provide a more detailed broad scale picture of the Hauraki Gulf benthos to be completed.

In terms of fish assemblages, the Hauraki Gulf supports a range of relatively common inshore species. Much of the inshore area is closed to bulk fishing methods and is thought to be an important juvenile fish nursery, of small snapper in particular. Currently there is not a clear understanding of why such areas are important to juvenile snapper, although it may be related to benthic food assemblages, or the more turbid waters providing some protection from larger fish predators.

3.5 Issues of scale with the QTC mapping system

One of the (anticipated) points to emerge from this work was that habitat types that are spatially restricted in extent, and receive only a small number of the total sampling units deployed (in this case ping stacks), may be swamped during data analysis by the presence of other acoustic classes that may be much more extensive, and therefore contribute the majority of the sample units. This was evident in the phase 1 sampling, where although the Motuihe and Ponui areas were identified as containing relatively high acoustic diversity, they did not fall out as distinctively different acoustic classes in their own right. In fact, they were actually habitat misclassified, through using ground-truth information collected from other areas of nominally the same habitat types. Nevertheless, they were successfully identified as areas of higher acoustic diversity (and thus benthic habitat diversity, as documented by the ground-truthing).

The second phase sampling of Motuihe and Ponui rectified these misclassifications (via smaller, more locally intensive surveys); this is one of the survey design issues to be considered when mapping at large spatial scales. Perhaps the best way of viewing this is in a hierarchical form, where broad scale surveys identify areas of high and low acoustic diversity, followed by higher resolution second phase data collection in the higher diversity areas, to maximise the precision and accuracy of the overall results.

The current survey was explicitly designed to provide appropriate datasets to explore such survey design issues, and the data will be used to identify the magnitude of these effects, and explore avenues for future survey designs to maximise information returns. We also intend to explore whether QTC View acoustic diversity can be used as a proxy for benthic biodiversity, given the now good datasets spatially linking acoustic and benthic diversity at broad spatial scales (this and the previous Firth of Thames work). This work is beyond the scope of the present contract, but is being funded as part of a different programme of research, the results of which will be made available to the Department of Conservation.

4. Conclusions

An acoustic survey of the Hauraki Gulf found six acoustic seabed classes using QTC Impact during the first sampling phase, representing various classes of muds. Second phase sampling revealed smaller areas of higher acoustic and habitat diversity, associated with areas of higher current flows. While both the Phase 1 and Phase 2 surveys identified areas of higher acoustic / habitat diversity, Phase 1 misclassified some non-mud areas as mud classes, due to data swamping. The more detailed Phase 2 mapping resolved these misclassifications.

Epifauna were in general quite sparse, but were more common in the higher acoustic diversity areas, more intensively mapped in the second phase. No green-lipped mussel beds were found, despite intensive sampling of areas where they were abundant half a centaury ago. Scallops, horse mussels, dog cockles and other bed forming bivalves were also uncommon.

Infaunal biodiversity is not directly reported on here, but benthic samples taken during grab sampling at Te Matuku are being processed separately for DOC. The others have been archived.

The fish fauna of the soft sediment habitats, as assessed by fisheries trawl surveys from 1982-2000, was composed of a suite of common inshore species, many of them of cultural, recreational and commercial value. Snapper, jack mackerel (*T. novaezealandiae*), red gurnard, and sand flounder dominated, with lesser numbers of barracouda, trevally, rig, kahawai and others. Many of these species, especially snapper, had population size structures where juveniles contributed significantly, demonstrating that the Hauraki Gulf (and the associated Firth of Thames) is an important nursery ground for a number of inshore species. Spatially, shallower areas contained higher abundances of fish, especially juvenile snapper. In particular, there appeared to be associations for snapper and trevally with acoustic class 6, which warrants closer investigation as to what might be underlying this association (e.g. benthic prey assemblages)

The intensity of sampling (run-lines at 1500 m spacing, most of the survey area), make this work a broad scale overview of the habitats present within the sampling area. Areas of higher acoustic and habitat diversity were also identified, embedded within this larger spatial framework.

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Table 1 - Ground truth stations, video and grab sample results

Phase 1

Station code	Acoustic Class Ph1	Acoustic Class Ph 2	Depth (m)	Grab sample description	Video description
1A	1		24.3	Fine clay, firm, compact. Small ammount sand. Small ammount shell fragments	Fine mud/sand, single burrow pits, tracks, luidea
1B	1		25.8	Fine clay, fairly soft, some shell fragments	
2CZ	2		3.5	Very soft brown layer on top. Firm grey mud underneath. Lots of shell - cockles	Mud
LN1	3		-	Soft mud. Some sand. Small shell fragments. Small sponge. Dead cup corals. Barnacles, worm tubes	sandy mud, some burrows
13-A	3		20.4	Very soft layer of brown mud over top of firmer grey clay. Small echinoderms. Tubeworms on surface.	
3B	3		45.1	Fairly soft brown mud with coarse fragments, sand, shell. Firmer grey mud underneath. Lots of shell & detritus - wood material.	
LN3	3		46.5	Fairly soft brown mud with coarse fragments, sand, shell - fairly firm. Firmer muds underneath. Some bryozoan.	
3A	3		45.8	Fairly firm mud with sand + shell fragments	Sandy mud, some small burrows
LN2	3		45.9	Soft, fine layer on top. Coarse, shell fragments.	sandy mud, some burrows
3C	3		41.5	Very soft mud on surface. Fine clay. Coarse shell fragments	Light levels too poor
4A	4		9.4	Very soft mud. Very fine. Shell fragments. Nothing on surface.	Mud, some burrows
2B	4		6.3	Very soft mud. Fine clay mud. Shell fragments. Adhesive balls of clay (up to golf ball size)	Mud, some burrows
4B	4		9.1	Very soft brown mud, layer on top	Mud, poor visibility
2C	4		4.8	Deeper layer of very soft brown mud on top. Thicker grey mud underneath. Shell fragments underneath. Lots of shell, cockles	Mud, poor visibility
4C	4		6.3	Fairly firm mud with sand. Some shell fragments. Lots of small crabs. Dead date mussel shells. Filaments on surface.	
4D	4		5.7	Fairly soft layer of fine mud + detritus. Lots of whole shells underneath. Cockles - some alive. Old mussel shells, crabs.	Mud, cushion stars
2D	4		6.4	Soft layer on top. Firmer underneath. Lots of shell underneath.	Mud, dog cockles at start, sloped burrows
5A	5		14.5	Fine clay, firm, compact. Very adhesive - sticky. Shell minimal. Lighter colour clay on top, darker below	Fine muddy sand, numerous multiple burrows, stingray

6D	5	17.1	Very soft mud. Minimal shell fragment	mud, big burrow depressions
2A	5	17.4	Very soft mud. Minimal shell fragment	mud, small flatfish, tracks, some burrows
5B	5	-	Mud. Some sand. Shell fragments. Fairly firm	Sand, Cocinastarias
5C	5	11.8	Very soft layer brown mud. Slightly firmer grey clay under shell fragments. Small echinoderms.	
5E	5	11.3	Very soft fine mud. Shell under. No firm mud under	Sandy mud, burrows
6A	6	18.2	Fine clay, adhesive, some shell fragments	Mud, tracks, Luidea
6B	6	16.4	Sandy mud, fine clay, shell fragments	
6C	6	15.3	Very soft layer brown mud. Shell fragments/ Small echinoderms. Firmer grety clay underneath. Nudibranch	

Phase 2

Whangaparoa

R1A	1	1 25.5	Fairly soft mud. Light brown clay on top. Firmer grey mud underneath. Some fine mud	Muddy sand, diatoms
R2A	1	1 24.8	Fairly soft mud with some fine sand. Minimal shell fragments	Muddy sand, diatoms
G1A	1	2 25.9	Fairly soft mud. Fine clay. No sand. Minimal shell.	Muddy sand, tracks, diatoms
G2A	1	2 26.4	Fairly soft mud. Fine clay. No sand. Minimal shell. Color light brown mainly + grey underneath	Muddy sand, tracks, diatoms
G3A	1	2 27.1	Fairly soft mud. Firmer underneath. Some fine sand. Miminal shell.	Muddy sand, tracks, diatoms

Motiuhe

M2A	2	2 25.5	Coarse sand. Lots of shell. Some sponge	Heavily armoured seafloor, hydroids, maoriculpus, dead shell
M2B	2	2 -	Coarse sand. Some clay. Lots of small shells	Mud with lots of shell. yellow finger sponges, dead scallop shell
M4B	2	4 20.5	Coarse sand. Lot of small whole shells. Shell fragments. Some clay. Filamentous 'weed' matt growing on top	Shell grit, lots of hydroids
M1A	4	1 6.3	Cobbles with coraline algae. Some seaweed. Lots of shells	Heavy maoriculpus cover (100%)
M1B	4	1 5.5	Sand (fine) with clay. Minimal shell fragments. Some worms	Hard sand/mud, horse mussels, tracks
M3A	5	3 7.3	Sandy (fine) with clay. Soft layer on top. Firmer underneath. Some shell fragments	Sand, small burrows, tracks
M3B	5	3 -	Lots of small whole shells. Held together by filamentous matt on top. Some worm tubes. Coarse sand	Hard silty mud, hydroids, cocasinaterias, maoriculpus, cushion stars
M4A	5	4 16.6	Fairly soft mud with sand. Minimal shell. 1 large horse mussel	Mud, some sloped burrows, large finger sponges

Ponui

P1B	1	3 32.5	Fine clay. Fairly cohesive. Minimal shell content	Big current, too much pelagic detritus

P3B	4	1 5.5	Soft mud. Thin brown layer on top. Minimal shell	Mud, some sloped burrows
P3A	5	1 2.8	Lots of epifauna on coarse shell fragments. Minimal clay. Coraline algae, lots of fauna	Shell armoured bottom
P2A	5	2 14.4	Fairly compact, cohesive mud. Soft on surface, firmer underneath. Minimal shell fragments	Mud, some burrows
P2B	5	4 10.1	Very soft grey mud. Minimal shell fragments	Mud, sloped burrows, tracks
P4B	5	4 10.6	Grabs 1 and 2 lot of large dead mussel shell, some tubeworms, 3 soft sediment, coarse fragments	Mud, dead dog cockles
P1A	6	3 47.5	Shell fragments. Coarse. Minimal clay. Some epifauna	Fine packed sand, sponges
P4A	6	4 9.3	Soft grey clay. Fairly cohesive. Minimal shell fragment. Slightly anaerobic smell.	Mud, some sloped burrows
P5A	6	5 18.9	Minimal clay. Coarse shell fragments. Lots of epifauna. Dog cockles, scallop, horse mussels	Horse mussel, heavy shell hash, scallops, encrusting sponges
P5B	6	5 17.6	Very soft mud. Fine brown layer on top of grey clay (grab overflowing)	No visibility
Te Makatu				
TM1A	4	1 4.3	Light thin brown layer on top. Very soft mud grey. Shell fragments underneath	Mud, lots of sloped burrows, cushion stars
TM1B	4	1 5.3	Very soft mud on top. Shell fragments underneath	Mud, some sloped burrows
TM1C	4	1 6	Thin layer of light brown mud. Very soft mud grey. Shell fragments underneath	Mud, lots of sloped burrows, cushion stars
TM3A	4	3 10	Shell fragments on surface. Soft mud.	Mud, large dead shell
TM3B	4	3 7.3	Fairly soft grey mud. Some burrows. Very little shell	Mud, sloped burrows
TM3C	4	3 7.9	Very soft mud on top. Firmer grey clay underneath. Shell fragments	
TM2A	4	4 16	Soft grey clay on top. Lots of shell fragments. Some firm clay underneath	Sandy mud, dead shell
TM2B	4	4 15	Some soft grey clay on top. Shell fragments. Firm clumps of clay.	Sandy mud, dead shell
TM2C	4	4 15.1	Very soft brown layer on top of soft grey mud. A lot of shell underneath	
TM4A	4	4 25.3	A lot of shell fragments in soft sediment	Heavy sand and shell (vis very poor), yellow sponge, anemones
TM4B	4	4 18	A lot of broken shell on surface. Soft mud and firm clay	Hard mud (?)
TM4C	4	4 17.5	A lot of shell fragments on surface + deeper. Clay. Coarse fragments	

Continue to next file: MCU4a