Intertidal and subtidal habitats of Doubtless Bay, Northland, N.Z.

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for

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Doubtless Bay, habitat mapping, aerial photography, habitat change, habitat map, biotypes

Client's Brief

- Collate and review information sources relating to historic research on marine natural features and ecology of the study site.
- Source and review available bathymetric data and historic aerial photos for the study site.
- Acquire and produce a current set of aerial photos for the shallow areas of the study area required for mapping in digital format suitable for geo-referencing in ArcGis.
- Carry out on-water survey where required using geographically referenced sonar, drop video, and diving methods to augment sub-tidal habitat information not obtainable from aerial photography. Data must be sufficient to map rocky reef edge at a scale of 1:50,000.
- Carry out more detailed investigation of a series of reference sites (a minimum of 5) which will provide information on biological communities and zonation by depth and more detailed ground-truthing of the overall survey. Information must have sufficient detail to allow mapping at 1:5,000 scale.
- Provide representative photos and/or video clips in digital format for each of the reference sites depicting the habitats therein. All digital photographs and video clips must be geographically referenced.
- Produce GIS habitat and biotype maps in collaboration with Information Services, Northland Conservancy.
- Provide a report for the project which includes an executive summary, introduction, methodology, habitat classification, map sets, discussion and conclusions. The report must: discuss accuracy and validity issues associated with the investigation and output of habitat maps; comment on biological communities and assemblies in the study area; and discuss the suitability of the study area as a marine protected area (MPA).
- Provide a review of identified information gaps relating to habitats and species assemblages of the study site.
- Provide recommendations for future research in the study area that would inform planning of MPAs in Northland.

Cover photo: Shallow algal-covered patch reefs are numerous across the gap between the mainland and a small island off Parekerake near Whatuwhiwhi. Dark (gravel) and pale (sand) alternating streaks out to the right of the island probably move in storms. They are aligned with the force of the waves.

Contents

Executive Summary

A habitat investigation of the Doubtless Bay area was completed in April - June 2005. The survey was done using a combination of drop video, side-scan and single beam sonar techniques. Aerial photographs were used to map shallow (< 12 m depth) habitats. A map of physical and biological habitats was produced at 1:50,000 scale covering an area of approximately 18,700 ha, excluding the major estuaries of Mangonui and Taipa. Seven smaller areas were mapped in more detail at 1:5,000 scale.

Major habitats recognised were:

- Intertidal habitats, including sandy beaches, gravel and boulder beaches, and solid rock shores. Limited areas of mangroves occurred in a few sheltered pockets.

- Subtidal habitats, including large areas of sand, gravel and muddy sand, as well as hard rock bottom. The rock substrates were occupied by biological assemblages forming a mainly depth-related sequence from shallow to deeper water, including shallow mixed weed, kina barrens, *Ecklonia* kelp forest, and deep reefs. A few sheltered shallow rock areas were occupied by tangle-kelp forest. Large areas of mixed rock and sediment substrates occurred at various depths.

It is concluded that marine habitats of Doubtless Bay are typical of those generally on the Northland east coast, but the large area of low reef in the central part of the Bay is a special feature which may have value as a nursery area for fish. The extensive occurrence of kina barrens suggests that snapper and crayfish have been seriously depleted.

It is recommended that the report and maps should be used widely to promote awareness within the community of the marine values of Doubtless Bay, and to foster moves toward improved management including establishment of marine protected areas (MPAs) and Marine Reserves as the central core of any restoration programme. Monitoring at a few key sites could involve the local community.

The complexity and diversity of habitats represented in Doubtless Bay suggest that the area is an ideal candidate site for some form of marine protection.

Introduction

Doubtless Bay is a semi-circular embayment on the northeast coast of Northland in the North Island of New Zealand (Figs. 1 and 1a), centred approximately at 34 degrees 55 minutes south, 173 degrees 28 minutes east. Prevailing winds are west to southwest, though northeast winds are frequent, particularly in summer. The main ocean current affecting the area is the East Auckland Current, a warm current of subtropical origin arising from eastern Australia. The East Australian Current originates in the Coral Sea and passes southward down the east Australian coast before turning east to cross the Tasman Sea as the Tasman Current. The Tasman current is rather diffuse but as it approaches northern New Zealand it becomes more defined and runs into the East Auckland Current which then passes southward down the Northland east coast and into the Bay of Plenty.

The East Auckland Current carries with it eggs and larvae of subtropical species picked up from eastern Australia, Lord Howe Island and Norfolk Island, some of which survive and settle on the Northland east coast and offshore islands. This gives the marine life of northeastern New Zealand, and the Doubtless Bay area, its distinct subtropical affinity, with numerous marine species in families which have their centre of distribution in the subtropical waters to the north of New Zealand. The main impact of the East Auckland Current is apparent in summer with the arrival in Northland of many large game fish species such as marlin, tuna, some sharks, and occasionally manta rays.

Water temperatures in the East Auckland Current and Doubtless Bay area range from approximately 22 degrees C in summer, peaking around February, to around 14 degrees C in winter with the minimum usually in July or August. These peaks and troughs vary a few degrees, and in their timing, from year to year, often associated with the El Nino/La Nina phases of the Southern Oscillation.

Underwater visibility in Doubtless Bay also varies throughout the year. Plankton blooms usually occur in spring, when visibility may drop to around three or four metres due to plankton in the water. Sometimes a secondary plankton bloom occurs in autumn. Water clarity in winter and in summer frequently reaches 15 to 20 m, particularly in the outer bay and around Knuckle Point, Berghan Point, and the reefs at Albert Rocks and Bastard Rock. Onshore winds or heavy swells can disturb bottom sediments and cloud the water, especially close to the shores and in the southwestern part of the Bay.

The southern coast between Aurere and Mangonui is more sheltered than the outer coasts near Knuckle and Berghan Points. Visibility along the southern shore is frequently reduced, particularly after heavy rain, by silt-laden water emanating from Mangonui Harbour, which can stretch westward along the coast clouding the water near Coopers Beach, Cable Bay and Taipa. West of Taipa visibility is usually better than further east.

Exposure to wave action generally increases from the inner bay to the outer bay along the Knuckle Point and Berghan Point coasts. These coasts are rocky, with many projecting points and reefs which afford shelter on their southern or western sides. Small rocky or sandy coves are common along both coasts.

Bathymetry of Doubtless Bay (see map section at end of report) shows mainly a gently shelving seafloor, increasing in depth to around 70 m midway between Knuckle and Berghan Points. Outside the confines of Doubtless Bay itself, the predominantly rocky and wave-exposed shores to the southeast and northwest drop steeply to over 50 m within a short distance of the coast. Within Doubtless Bay the seafloor is by no means a regular slope, with numerous rocky reef areas with variable relief over a large proportion of the central Bay. The nature of the seafloor and the marine habitats present in Doubtless Bay form the basis of the investigations and results described in this report.

For any planning of spatial use of land or sea a basic knowledge of 'what is there' is fundamental to progress. This report provides a basic understanding of the seabed habitats, a description of their nature, and maps their distribution within Doubtless Bay. It is our hope that this report will help facilitate the planning process, and in particular MPA planning, for marine areas of the Bay. It may also encourage or assist further ecological research and management of the Bay's natural marine resources.

Review of previous work

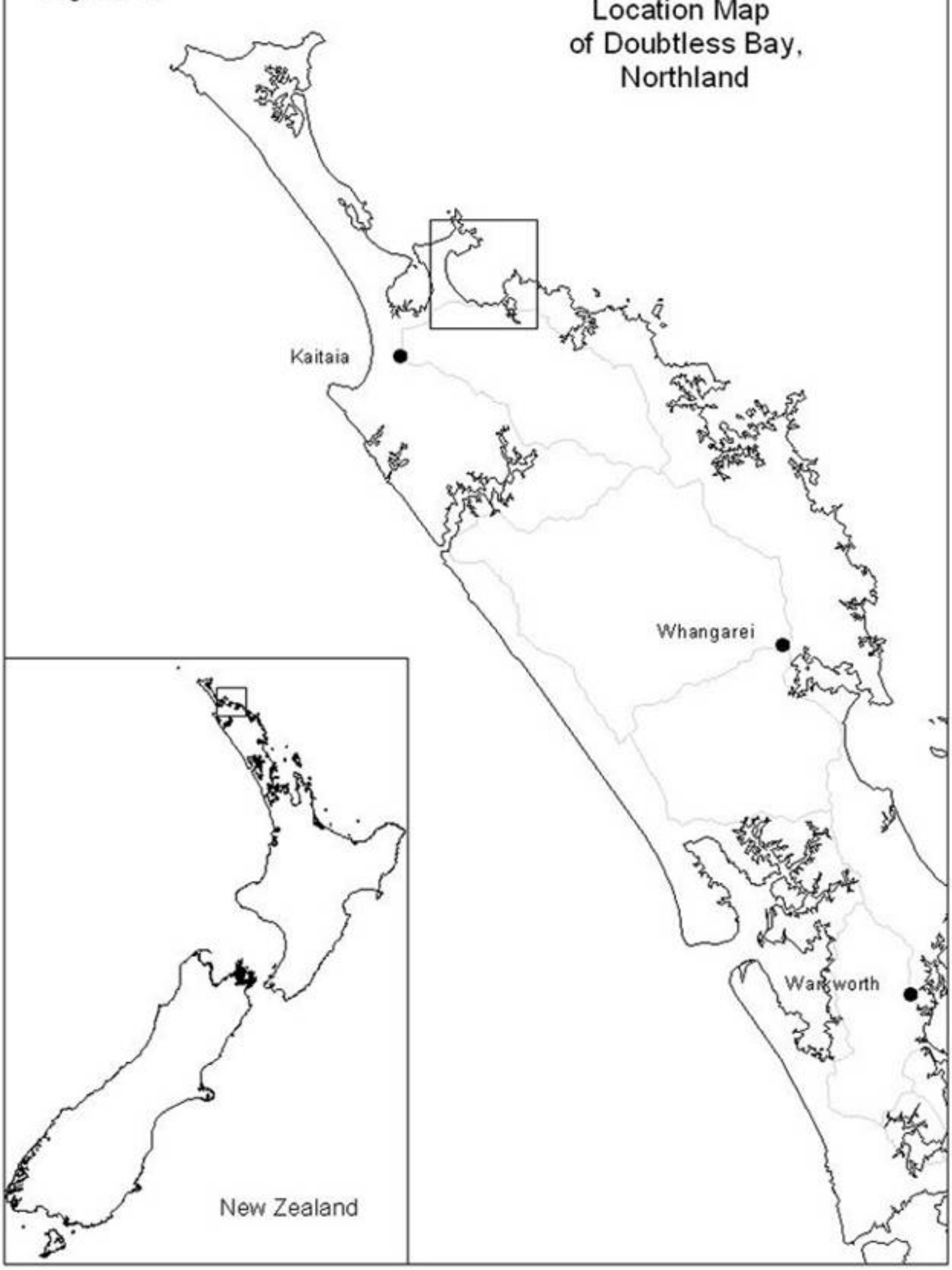
The marine area of Doubtless Bay has received little attention from marine researchers in the past. A few studies have investigated various aspects of marine life around Cape Karikari, such as fish population studies (Willan et al. 1979), and intertidal and sublittoral zonation patterns (Grace and Puch 1977). Shaw and Maingay (1990) included consideration of Doubtless Bay and Mangonui Harbour in their Coastal Resource Inventory for the Department of Conservation.

More recent studies looking at broad issues have included a few sites within Doubtless Bay. For example, Brook (2002) included four sites between Whatuwhiwhi and Knuckle Point in his study of the biogeography of reef fishes in northern New Zealand, and noted an increase in species richness from the shallow sheltered western site to the deeper more exposed Knuckle Point site. Shears and Babcock (2000) included two sites east of Brodie's Creek in their work on the rocky coastal community types of northeastern New Zealand. Strangely, Shears and Babcock specifically noted an absence of the shallow exposed brown seaweed *Carpophyllum angustifolium* from these sites and other sites on Cape Karikari, but Grace and Puch (1977) found it zone-forming on the Moturoa Islands, and in this study we found it abundant in the surge zone immediately south of Knuckle Point.

As part of a review of the natural marine features and ecology of Northland, Morrison (2005) included some discussion of the shorelines and marine life inside and outside Doubtless Bay. Other recent work relates to proposed Aquaculture Management Areas (AMAs) in northern New Zealand. Haggitt and Mead (2004; 2005) investigated an area inside Mangonui Harbour as a potential site for intertidal aquaculture, and found the species abundance and diversity markedly lower than in more northern estuaries sampled such as Houhora.

The only recent study specifically of Doubtless Bay is that by Makey (2005), which looked at fisheries and the social and cultural implications of various reform options for management of the marine areas of Doubtless Bay.

Figure 1.


Location Map
of Doubtless Bay,
Northland
Kaitaia
Whangarei
Warkworth
New Zealand

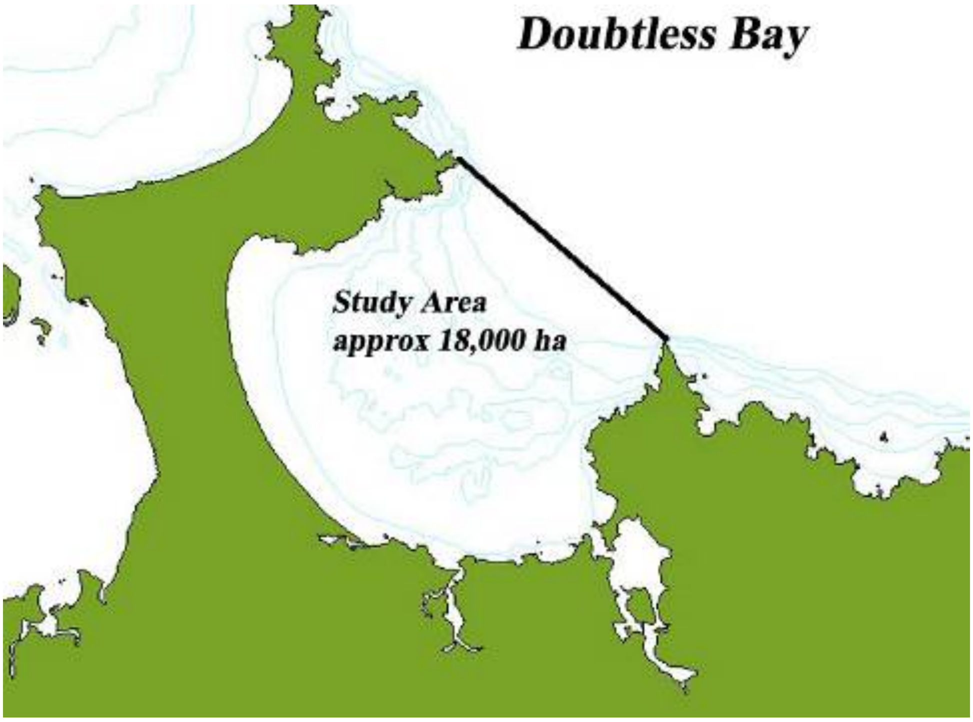


Figure 1a. Doubtless Bay, Northland, showing the study area.

Methods

Habitat Classification and Descriptions

The habitat classification used in this study is based on work by Ballantine et al. (1973), Ayling (1978), Ayling et al. (1981) and Grace (1981; 1983). The method adopted in this study closely follows the classification and methodology adopted in the Kerr and Grace (2005) Mimiwhangata habitat mapping report. The habitat descriptions generally use a combination of physical substrate characteristics and groupings of habitat-forming macro-algae. Qualitative habitat descriptors were used to enable rapid mapping of the study area using a combination of sonar and video methods, rapid sediment sampler, diving, and aerial photography.

Table 1 compares historic habitat classifications, ranging from the earliest work of Ballantine et al. 1973 at Mimiwhangata to a very recent classification (Shears et al. 2004), and including the classification adopted for this study.

The Shears et al. (2004) study examined the degree of concordance between qualitative habitat descriptors and quantitative species data from various locations along the northeast coast. They concluded that qualitative habitat descriptors for rocky reefs do accurately define biologically distinct species assemblages and are therefore an efficient means of mapping subtidal rocky reef habitats. It is worth noting that Shears et al. (2004) describe five additional habitats on the shallow reef not used in this study: mixed algae, red foliose algae, turfing algae, *Caulerpa* mats and encrusting invertebrates. While all these habitat assemblies occur at Doubtless Bay, all but turfing algae occur in patches or mixed areas at spatial scales too small to map with the methods chosen for this study. Turfing algae would make up some of the habitat classified as 'kina barrens' in this study. The two algal types can not be distinguished from each other in aerial photos, which were used as the basis for mapping shallow areas.

Some of the historic classifications did not deal with intertidal or sediment-bottom habitats.

TABLE 1. HABITAT CLASSIFICATIONS

Doubtless Bay (this report)	**Mimiwhangata** Kerr and Grace 2005	**Northeast NZ** Shears et al. 2004	**Hauraki Gulf** Grace 1983	**Paparahi** Grace 1981	**Leigh** Ayling 1978	**Mimiwhangata** Ballantine et al. 1973
Intertidal Habitats						
Sandy beaches	Sandy beach	Not considered	Not considered	Sandy beaches	No equivalent	Light-coloured sand beaches
Gravel beaches	Gravel beach	Not considered	Not considered	Gravel beaches	No equivalent	Dark-coloured sand beaches
Rocky shores	Rocky shore	Not considered	Not considered	Rocky shores	No equivalent	Solid rock shores
Mangroves	Not present	Not considered	Not considered	Not present	Not present	Not present
Subtidal Habitats						
Sand or mud	Sand/mud	Not considered	Not considered	Sand (sand/mud)	Sand & gravel (in part)	Clean sand
Gravel or cobbles	Gravel/cobble	Not considered	Not considered	Gravel (gravel/cobbles)	Sand & gravel (in part)	Coarse gravelly sand, gravel
Gravel or cobbles	Gravel/cobble	Cobbles	Not considered	Cobbles	Cobbles (in part)	Coarse gravelly sand, gravel, cobbles
Shallow mixed weed	Shallow mixed weed	Shallow *Carpophyllum*	Shallow mixed weed	Shallow mixed weed	Shallow broken rock	Shallow exposed zone
Urchin (kina) barrens	Kina barrens	Urchin barrens	Rock flats	Rock flats	Rock flats	Medium-depth without kelp
Tangle-weed forest	Tangle-weed (kelp) forest	*Carpophyllum flexuosum* forest	Kelp forest (in part)	*Carpophyllum flexuosum* forest	Not present	Shallow sheltered zone
Ecklonia forest	*Ecklonia* forest	*Ecklonia* forest	Kelp forest (in part)	*Ecklonia* forest	*Ecklonia* forest	Medium-depth kelp bed
Deep reef	Deep reef	Not considered	Very deep reef	Not present	Sponge garden (in part)	Very deep reef
Mixed sand and rock	Deep reef mixed sand and rock (part)	Not considered	No equivalent	No equivalent	No equivalent	No equivalent

The area investigated in the present survey (Fig. 1a) includes the entire marine area of about 18,700 ha southwest of a line between Knuckle Point in the north to the small islands off Berghan Point to the south, but does not include the estuaries at Aurere, Taipa or Mangonui. The work was completed in stages between April and June 2005. Aerial photography was used to map habitats in shallow waters (< 12 m depth). In deeper waters sonar methods were used. In both cases video techniques and diving were used to ground-truth the resulting habitat classification. Information from previous habitat maps and dive records from other investigations (Kerr and Grace 2005) were also referred to. In association with the sonar surveys the soft bottom areas were investigated at spot sites with a simple rapid sediment sampler. The description of the various methods and equipment used follows.

Survey vessel

All work in this investigation was carried out from a 4.2 m Mac boat powered with a 50 hp outboard. The sonar equipment described below is mounted in the boat and transducers for both machines are mounted on the bottom edge of the transom either side of the motor.

Side-scan sonar

The side-scan unit used was a Humminbird 987-C SI. The unit has side-scan GIS capability as described in the following specification:

- Side Image Coverage area (max 200 m swath 0-30 m depth) of the bottom, 160 degrees @-10 dB in 455 kHz.
- 2D conventional sonar depth capability 780 m,74 degrees @ -10 dB in 50 kHz & 20 degrees @ -10 dB in 200 kHz.
- 7" sunlight viewable colour display with 480V x 854H resolution TFT LCD screen technology (allows easy screen capture w/ digital camera, i.e. no flicker).
- Dual frequency 50/200 kHz sonar conventional 2D sonar, side image sonar 262 kHz / 455kHz.
- 750 Watts RMS, 6,000 Watts PtP (200 kHz) and 1,000 Watts RMS, 8,000 Watts PtP (50 kHz) Power Output, 63 m target separation.
- Dual microprocessors and triple channel sonar transmitter/receiver.
- Full screen track-plotter, 3D track and split screen sonar/track with adjustable split.
- Programmable view presets access important screens with one touch.
- Plug & Play Compatibility and PC Connection.
- Accelerated Real Time Sonar™ operates at up to 40 times per second to instantly capture the action under the boat. Signal displayed in window as actual sonar return intensity plotted against a vertical depth scale.
- Freeze Frame pauses the sonar scroll for detailed inspection of the screen.
- Totally automatic operation or totally manual operation with upper and lower range control.
- One-touch Zoom with 2 x, 4 x, 6 x, and 8 x zoom levels.
- Adjustable chart speed.

Multibeam 3D sonar

A second sonar unit utilised for the project was a Humminbird 947c 3D unit. This machine had a multi-beam arrangement and produces a 3D swath image on its screen. It also has conventional 2D sonar images and the Humminbird 'real time sonar' window display. This second system was used as a check on the interpretation of the side-scan unit and was especially helpful in the interpretation of soft sediments. It was a further advantage to have the track-plotter capability on this second machine so that the side-scan unit was totally free for side-scan imaging.

- Same GPS, track-plotter and general features as the Humminbird 987c SI unit described above.

- Dual frequency 83/455 kHz arranged in a 6 beam configuration.
- Depth capability 3D 75 m, 2D 330 m.
- Area of coverage 74 degrees @ -10 dB in 83 kHz & 53 degrees @ -10 dB in 455 kHz.
- 750 Watts RMS, 6,000 Watts PtP (200 kHz) and 1,000 Watts RMS, 8,000 Watts PtP (50 kHz) Power Output, 63 mm Target Separation.
- Accelerated Real Time Sonar™ operates at up to 40 times per second to instantly capture the action under the boat. Signal displayed in window as actual sonar return intensity plotted against a vertical depth scale.
- Freeze Frame pauses the sonar scroll for detailed inspection and selection of georeferenced target points via cursor control.

GPS and Georeferencing data collection

For all point and track information in the study a Garmin 12 GPS unit was used. The position accuracy of this unit given by the manufacturer is 15 m. Our own checks of accuracy of the unit by returning to known points indicated an accuracy of 5-7 m. At the end of each day data was downloaded into a PC laptop into Fugawi 3.4 software for processing to Excel spreadsheets. The track-plotter function in the Humminbird 947c unit was used for basic navigation and the setting up of target points for sonar and video drop positions.

Rapid Sediment Sampler

As a quick field check on interpretation of soft sediment characteristics from the sonar image, a sediment sampling system was devised based on a method used on old sailing ships. In the old days depths were sounded using a lead weight and measured line. A sample of the bottom material was collected during soundings by smearing tallow on the bottom of the lead sounding weight, a small sample of the sediment sticking to the tallow when the weight hit the bottom. We copied the technique by using a lead weight smeared with margarine, dropping the weight to the bottom and retrieving it quickly using a casting rod and reel. This minimised sampling time but enabled retrieval of sufficient sedimentary material to characterise the substrate type. In some cases photographs of the samples were taken (Fig. 5).

Drop video equipment

The video drop apparatus was a Sony TRV6e mini DV camera mounted in a simple, robust housing built by us from a recycled scuba cylinder and Plexiglas sheet material. The housing was arranged with a bottom weight attached to a one metre line attached to the bottom edge of the housing. Another line was attached to the top edge of the housing extending upwards to a series of floats starting at one metre above the housing (Fig. 6). By adjusting these attachment points, weights and floats, we were able to arrive at an arrangement that allowed us to 'feel' when the unit hit the bottom. We would then let out 3-5 m of slack in the line. The unit then hung vertically held by the floats with the camera approximately one metre above the bottom. We found that the arrangement would naturally rotate the housing in a circle or semi-circle, effectively panning the camera and greatly increasing the viewing area. We also devised a method of bouncing the unit along the bottom for short distances which also increased the area photographed. The housing unit had no external camera controls. The camera was simply turned on, set on automatic focus and exposure, placed in the housing and deployed. A remote on/off device was used to place the camera on standby while on the surface between drops. Using this system drops could be made with a minimum of time and effort, allowing many drops during a field work session.

Manta board video

In some circumstances we used a georeferenced manta board survey technique which gives more coverage than the drop video method. This technique is adapted from a similar technique used successfully by Grace (1981) at Paparahi, and by Francis and Grace (1986) at Great Barrier Island. The manta board is a simple flat piece of marine plywood attached by a bridle to a thin tow line which is attached to the stern of the boat. A diver holds on to the front of the board and is towed at about two knots about 20 to 50 m behind the boat. By tilting the front of the board upward or downwards the diver can use the board like a paravane, and cruise above the bottom following the bottom contour observing marine habitats. Grace (1981) used a small rotor-driven distance log attached to the board, and made habitat notes on a writing pad attached to the board. The simple design of the board enabled it to be controlled with one hand, leaving the other hand free for writing notes while travelling over the seabed. Navigation was predetermined by having the boatman travel in a straight line between points on a map.

The new adaptation of this technique used the hand-held GPS on the boat for navigation and recording the route travelled, and a small underwater video unit pointing forwards attached to the top of the manta board for recording an image of the seabed covered. The camera used was the same one as in the video drop apparatus described above, but in a smaller purpose-built housing bolted to the manta board. By careful time-keeping and setting a constant tow line length (generally 50 m) it was possible to plot the tow route and relate it to the video image to within a few metres. Using this technique it is possible to make a continuous video record of habitats along a line several kilometres long.

Side-scan sonar, drop video survey method

Following initial analysis of bathymetry and aerial photos, areas of potential reef were marked on a work map. A system of parallel survey lines was then planned, the lines extending beyond the potential reef areas to try to ensure reef edges were detected and to pick up any outlying patch reefs nearby. The lines were at approximately 200 m spacings in the initial survey. The survey by necessity was at times adjusted in the field to suit the underwater topography, with most effort being focused in complex areas.

At each point along the survey track, where the substrate/habitat classification was judged to have changed, the coordinates of the point were recorded. The track was also recorded for all survey lines. The lines and 'change points' are illustrated in the 'Tracklines and Waypoints Map', (see map section). The data for all survey points is included in Appendix 1. This subjective classification interpretation was informed by diving experience in some of the areas, and by previous experience and testing with the sonar equipment. Where rock structures were visible, representative areas were studied by measuring the sonar 'shadows' cast by the vertical structure. This gives a relatively accurate calibration of vertical features (Fish and Carr 1990). Classification of the side-scan image and sonar imagery was ground-truthed with drop video, scuba and snorkel dives, manta video and rapid sediment sampling technique during the course of the investigation to further ensure the interpretation of the sonar images remained accurate. As a further check in the system, side-scan screen images of areas of particular interest were captured on digital video and archived on DVD backup disks as MPEG2 video files. The screen image has a latitude and longitude coordinates window and the video has a lineal timecode so that any location on the survey run can be located and checked or further analysed. The classification used for the initial sonar survey was as follows:

1. high relief rocky reef with vertical structures > 3 m (hr)
2. low relief rock reef (lr)
3. mixed reef and soft sediments (m)
4. gravel/cobble (g)
5. sand/mud (s)

Examples of the side-scan screen image for a high relief rocky reef area and a sand area changing to low relief rock are shown in Figs. 7 and 8.

Following the initial survey work, results were brought into an ArcView GIS system and mapped. The initial survey yields an approximate reef edge. Analyses of the initial survey maps allowed further sonar survey lines to be run with the objective of mapping reef edges and habitat changes to less than 200 m accuracy. In the areas determined as reference areas (see description below) the survey effort (line spacing) was typically closer to ensure that precision in deeper areas came down to approximately 100 m with the sonar. In shallow areas where fine resolution was possible from the aerial photos, precision came down to about 10-15 m.

From the mapped sonar survey information a drop video survey was designed. The video survey target points were selected to identify:

1. all the major physical habitat types
2. inconsistent interpretations between the side-scan and single beam sonar surveys
3. areas where it was likely habitat boundaries were still not covered
4. reef areas where major biological boundaries were likely to occur
5. areas to ground-truth the analysis of aerial photography

This survey served the function of checking the sonar interpretation in replicate areas.

Secondly, video drops were arranged across depth profiles in each reference area for the purpose of identifying depth dependent zonation patterns of biological communities as defined in the Mimiwhangata study (Kerr and Grace 2005). At some locations, in order to gather more detailed information than the video drop produces, we used a towed manta board with a mounted video camera, snorkel swim and scuba dive techniques. The data for the video drops and manta tows are included in Appendix 1.

Aerial Photography

Available aerial photographs were assembled and reviewed. Photo series taken for Doubtless Bay in 1993 and 2003 held by the Northland Regional Council (NRC) were found to contain some useful images of subtidal structures and habitats. However these photos were only of high quality for habitat mapping in a small proportion of the Doubtless Bay area. On June 7 2005 conditions were adequate for aerial photography and a new set of photographs were taken according to the specifications described below. The photos were georeferenced with the use of the NRC 2003 aerial photos and Image Analyst ArcView GIS software.

Aerial Photography Planning Details

Hardware, camera settings, and other technical details were as follows:

Camera:	Nikon D70 digital SLR
Lens:	35-70 mm zoom lens, generally set on 50 mm
Focus:	Fixed on infinity
Sensitivity:	Digital ISO equivalent 200
Shutter priority:	1/250 second

File type(s):	Fine resolution jpeg at 6MB file size
Download time:	3 seconds per image
CF card size:	1 GB
Images per card:	About 150

Plane:	Piper with camera port in floor
Height:	6,000 ft (though some were flown at 3,000 ft)
Speed:	120 mph
Picture width:	900 m on ground, across flight path (at 6,000 ft)
Picture length:	600 m on ground, parallel to flight path (at 6,000 ft)
Picture centres:	500 m intervals on the ground
Picture overlap:	About 100 m each end of picture
Time interval:	9.3 sec. between shots at 120 mph gives 500 m centres
Flight plan:	Flight north from Onerahi, then start at Berghan Point, follow coast southwards flying about 300 m seaward of the shoreline. Osprey Head, Mangonui Harbour, Coopers Beach, Cable Bay, Taipa and estuary, Tokerau Beach, Whatuwhiwhi, Knuckle Point. If conditions allow continue around Cape Karikari to Karikari Bay, then cut across peninsula to Whatuwhiwhi, then track along shallow edge of the two large reefs in the middle of Doubtless Bay. If the reef edge is visible cover as much of the edge as possible. Also target other small potential reefs, as suggested by the fair chart, in water shallow enough to get visual information on the seafloor. Return flight to Onerahi.

On the day several changes were made to the planned flight because of the presence of clouds rolling in and obscuring some areas. Some areas we had hoped to photograph became impossible because of low cloud. In the areas we did manage to cover, however, excellent underwater detail was visible in the photographs.

Sourcing and Analyses of Original Navy Fair Charts for Study Area

Navy fair charts for Doubtless Bay, from surveys by the NZ Navy Hydrographic Branch from 1972 to 1974 (mostly from the vessel HMNZS Lachlan) were obtained from Land Information NZ. Initial scanning and georeferencing of the fair charts was completed with a digital camera and Fugawi software system. It is fortunate that the quality and resolution (i.e. spatial frequency of soundings) for the Doubtless Bay area is particularly good. For the final bathymetry layers the fair charts were digitised and georeferenced in an ArcView GIS system.

Bathymetry Data Correction to Chart Data

During our side-scan surveys, depth was recorded for all data points along with time of day. There are two sources of error that affect the precision of the data. These are variations in relation to chart datum relating to the stage of the tide and error in the sounder reader as a result of boat movement up and down due to swell. We have recently put in place an operational procedure to correct or quantify these errors. For the tide correction to chart datum factor we have written an Excel spreadsheet program that transforms the field depth data to chart datum levels. This program uses published tide times and levels for the nearest secondary tide station and a set of formulas based on a translation of a Cosine curve. We have checked the accuracy of this program against US based tide prediction program and the calculation error is within 100 mm for any time in the tide cycle. We cannot eliminate the boat movement error, but we can record the movement routinely over the course of the survey work. This figure will then become one aspect of the error that goes along with the data in a metafile. In practice at the back of the boat, where the sonar transducers are mounted, there is minimal movement in the vertical plane in the conditions we normally work in. Typically swell heights were less than half a metre while sonar surveys were done. The swell heights we encountered are listed in Appendix 2 and bathymetry data is included in Appendix 1.

Habitat Mapping

Sonar, video and all ground-truthing information were brought together in a series of GIS layers. The georeferenced June 2005 aerial photographs were adjusted for light/dark balance and contrast in a graphics programme to provide maximum visibility of underwater structures. The photos were then added as a further layer in the GIS system. A series of work maps were created from all the line and point data, which was overlaid on the aerial photo layer where this was helpful. In the shallow areas, aerial photographs allowed very close resolution of detail in the order of 3-15 m. A line indicated on the map in Fig. 4, (see map section) shows the seaward depth extent of the usefulness of the aerial photos for the mapping exercise. Beyond this line the distance between the sonar images combined with the video points determined the accuracy of the sonar-derived habitat polygons. In the final mapping exercise all the information was assessed collectively to make the best possible approximations of the habitat polygons which were drawn free-hand on hard copy work maps (1:5,000 scale). The hand-drawn habitat polygons on the work map were then digitised through a combination of scanning and computer drawing methods and transferred to the GIS system to produce the final habitat map.

Depth boundaries of the various habitats defined were determined by a combination of drop video, scuba diving, snorkelling, manta tows, and knowledge of similar habitats at Mimiwhangata (Kerr and Grace 2005). Care was taken to determine these boundaries at various locations throughout Doubtless Bay, paying particular attention to changes in depth boundaries related to changes in wave exposure from the outer to the inner parts of the Bay. Beyond the depth at which detail was visible on aerial photographs, the actual line on the map was set by interpolation along depth contours derived from the digitised bathymetry based on the original navy fair charts, and also bearing in mind changes in bottom substrate type derived from the side-scan survey lines. In shallow water where good detail was available from aerial photographs, habitat boundaries were drawn directly on aerial photo prints as described above.

For final presentation, habitat maps initially drawn at 1:5,000 for most areas were combined and scaled to 1:50,000 to cover the whole of Doubtless Bay on a convenient paper size (approximately A2). A reduced A3 size map of the entire study area is included in the back of the report.

Reference Site 1:5,000 scale mapping

Seven areas were selected for presentation as more detailed habitat maps at 1:5,000 scale. The areas are indicated on the map in Fig. 4, (see map section):

1. Brodie's Creek
2. Whatuwhiwhi
3. Parakerake
4. Aurere
5. Chuck's Cove
6. Onete

7. Fairway Reef

Selection of these sites was based on consideration of the following criteria:

1. Areas where good detail was visible in shallow water in aerial photographs;
2. Feature sites of interest to local communities;
3. Range covering the full variety of shore types and aspects (except the major estuaries), including one offshore reef system (Fairway Reef) and some deeper water features;
4. Spread widely in Doubtless Bay.

Techniques used included aerial photography, side-scan sonar, single beam sonar, 3D sonar display, drop-video, diver transects, diver manta board tows, spot dives, and direct observations from the boat while cruising slowly in shallow water. The final selection and balance of survey tools and spatial layout of the work was completed following consideration of the information from the initial survey.

Results

Habitat map

The habitat maps included in this report represent the summation of all the information assembled in this investigation. The total area mapped is approximately 18,700 ha. The mapped area includes all shorelines and seabed features landwards of a line from Knuckle Point to the small island off Berghan Point at the entrance to Doubtless Bay, but does not include the two major estuaries of Mangonui and Taipa, or the small estuary at Aurere.

Marine habitats of Doubtless Bay are mapped at a scale of 1:50,000 on the A2-size fold-out map inserted at the back of this report. The habitat classification used is shown in Table 2, which includes the area of each habitat occupied within the mapped area, as well as the percentage of the mapped area covered by each habitat.

TABLE 2. DOUBTLESS BAY MARINE HABITATS.

INTERTIDAL HABITATS		AREA OCCUPIED (Hectares)	PERCENTAGE OF MAPPED AREA
	Sandy beaches	162.4	0.87
	Gravel beaches	10.9	0.06
	Rocky shores	79.4	0.42
	Mangroves	2.2	0.01
SUBTIDAL HABITATS			
	Shallow mixed weed	138.0	0.74
	Urchin (kina) barrens	111.6	0.59
	Tangle-weed forest	6.0	0.03
	Ecklonia forest	570.0	3.04
	Deep reef	109.1	0.58
	Mixed sand and rock (kina barrens)	37.2	0.20
	Mixed sand and rock (*Ecklonia* forest)	1917.0	10.21
	Mixed sand and rock (deep reef)	1390.9	7.41
	Sand or mud	12208.0	65.01
	Gravel or cobbles	2030.7	10.82
TOTAL		18773.4	99.99

By far the greatest part of the mapped area is occupied by subtidal sand or mud (65.01%), with coarser gravels or cobble areas comprising a further 10.82%. Rock or rock-sediment mixes comprise 22.8% of the mapped area, only 4.98% being solid rock habitats. The rock and rock-sediment mixes thus make up only a small proportion of the Doubtless Bay seabed, but have a disproportionately large ecological importance because of their high topographical complexity and consequently high biological diversity.

Intertidal habitats occupy only 1.36% of the mapped area, but are interestingly the only habitats seen by the vast majority of people, with about two-thirds being sandy beaches.

Habitat descriptions

Intertidal habitats.

Sandy beaches

There are many sandy beaches in the Doubtless Bay area, the largest being Tokerau Beach at approximately 15 km long. Other smaller sandy beaches occur in the south of the Bay - Taipa, Coopers Beach, Cable Bay, and Hihi Beach - and Whatuwhiwhi in the north. There are also a few small sandy beaches in embayments on the predominantly rocky Berghan Point coast, and between Whatuwhiwhi and Knuckle Point. Biologically the sandy beaches generally support little life with species abundance and diversity low compared to the other habitats except gravel beaches. Apart from sand hoppers on the drift line, marine life consists of several species of worms and tiny crustaceans on the middle or lower parts of the beaches. Tuatuas have been reported from the northern end of Tokerau Beach, but were not noted during this survey, and wash-ups frequently occur of various surf clams and other molluscs from shallow water. The small estuary at Brodie's Creek on the Whatuwhiwhi coast contains some very sheltered muddy sand shores with cockles and mangroves in appropriate places.

Gravel beaches

Many of the smaller beaches in the area consist of gravel and pebbles, or gravel with sandy areas at certain tidal levels. There are many small gravel beaches in coves on the rocky shores on the northern and eastern sides of Doubtless Bay. This habitat is hostile to macro-invertebrates since movement of gravel and pebbles even in very light wave action causes mechanical damage to organisms living there. There are a few boulder beaches, particularly on the outer more wave-exposed shores of Berghan Point and Knuckle Point.

Rocky shores

A high proportion of the northern, eastern and southern shorelines of Doubtless Bay consist of hard rock of volcanic origin, criss-crossed with numerous joints. These joints are zones of weakness along which preferential erosion occurs. Consequently many rocky shoreline features, on both a large and small scale, are aligned parallel to the jointing system within the rocks, and some can be seen in the aerial photographs. Marine life on the rocky shores is rich and varied. The details of distribution and types of animals and plants present are controlled mainly by tidal level and the degree of exposure to wave action (Morton and Miller 1973). There is a wide range of exposure to wave action along the Knuckle Point and Berghan Point coasts, exposure generally decreasing westward and southward, but complicated by the presence of numerous embayments separated by projecting headlands. There is a correspondingly wide range of patterns of marine life. Some of the more familiar forms of marine life are rock oysters on the most sheltered shores, and surf barnacles on the more exposed rocky points and headlands. There are also examples of rocky shores where the major patterns of life are further modified by shade, sand scour, standing water in rock pools, and freshwater runoff. Small colonies of green lipped mussels *Perna canaliculus* occur on rocky shores in the Bay, notably in the Aurere area, some reefs and headlands between Taipa and the entrance to Mangonui Harbour, on Albert Reef, and sporadically elsewhere.

Mangroves

Mangroves are extensive in Mangonui Harbour and Taipa estuary, and in the Aurere estuary, but these areas are not included in this study. The small estuary at Brodie's Creek on the Whatuwhiwhi coast contains areas of mangroves in its upper reaches. In Chuck's Cove, a small area of large mangroves occurs in a small creek, and scattered individual mangrove trees occur in sediment pockets on the rocky and gravelly shores.

Subtidal habitats.

Sand or mud (depth range 0-70 m+)

Sand extends well offshore from most of the sandy beaches, and most of the sheltered rocky shores drop quickly on to sand below low water. In deep water beyond about 50 m, where the influence of storm waves is rarely felt, the sediment is muddy fine sand, and occupied by characteristic deeper water species. In shallow water, generally less than 10 m, the sandy bottom is characterised by ripple patterns - a series of small wave-induced parallel wave forms on the surface of the sand, except in the most sheltered areas. There is generally far more animal life in the permanently submerged sandy area than on the sandy shores, partly as a result of the greater stability and lack of violent wave action in sub-tidal areas. Coarser sand frequently supports dense beds of the morning star shell (*Tawera spissa*), a bivalve shellfish 20 to 25mm in length which in places reaches densities exceeding 5,000 per square metre. They are particularly common near reefs along the coast east of Whatuwhiwhi.

Off Tokerau Beach a variety of surf clams occurs, common species including the coarse-ringed *Dosinia anus* and the frilled venus shell *Bassina yatei*, while the burrowing gastropod *Struthiolaria papulosa* may also be common. The paddle crab *Ovalipes catharus* frequently occurs in shallow water off the sandy beach. Historically scallops and horse mussels have been found along Tokerau Beach, particularly toward the southern end, in depths from about 10 to 20 m.

Sand offshore from Tokerau Beach, and southeast of Whatuwhiwhi, is often streaked with elongated patches of gravel on a scale too small to map at the working scale. The aerial photo (Parakerake), and the cover photo, clearly show dark and light areas toward the south, the dark being gravel and the pale being sand. The distribution of sand and gravel areas probably changes in storms, with individual gravel areas being temporary in nature. The sand/gravel streaks are clearly aligned with the direction of wave movement.

Gravel or cobbles (depth range 0-60 m)

Sediments dominated by gravel and cobbles are less widespread than those characterised by sand or muddy sand. The major gravel areas are found west of the exposed outer Berghan Point coast where steep rocky reefs drop down to flatter gravel areas, and seawards of the extensive reef and mixed rock and sediment zones near the middle of the Bay. Another large area of gravel stretches west of the Berghan Point coast and across to the south of Fairway Reef. Smaller areas of gravel occur south of Knuckle Point, and sporadically amongst reef areas in the northern half of the Bay, and inshore east of Whatuwhiwhi.

Small areas of larger cobbles were noted in very shallow water immediately off two sandy beaches near Whatuwhiwhi, and in deeper water (around 30 metres) during a dive just south of Knuckle Point.

Gravel sediments often have large ripples, some being up to 300-400 mm tall and one metre from crest to crest. Often gravel ripples are clearly seen in the side-scan sonar images. An example of a gravel area with large ripples is shown in Fig. 9, which is a still grab from drop video. The more mobile gravel bottom areas are usually poor in macro-invertebrate life, but where the bottom material tends to be more stable dense populations of some sturdy bivalve shellfish are found. The morning star shell (*Tawera spissa*) is equally at home in these areas as it is in coarse sand, but in gravel may also be accompanied by the purple sunset shell (*Gari stangeri*), the small dog cockle (*Glycymeris modestus*), and sometimes *Dosinia maoriana.*

Under normal conditions a cobble bottom is fairly stable, but during storms some of the cobbles and pebbles may move. This semi-stability enables some types of faster-growing seaweeds (often red algae) to survive on the more stable rocks, but theirs is a precarious existence as, sooner or later, the rocks will move in a storm and the algae will be destroyed.

Shallow mixed weed (depth range 0-3 m in shelter; 0-7 m in exposure)

This habitat occurs on rocky reefs between low water and about 7 m depth, and in increasing shelter is often restricted to the shallower part of this range. The rocky substrate is often very broken and dissected, with tumbled boulders, ridges and crevices. Several species of large brown algae are visually dominant. The most abundant of these is flapjack kelp (*Carpophyllum maschalocarpum*). Small plants of kelp (*Ecklonia radiata*) occur in the deeper areas or more sheltered parts of the zone. Where wave action is moderate or heavy, the upper part of the zone is characterised by a fringe of *Carpophyllum angustifolium*, which forms a dense swirling carpet, the vertical extent of which is determined largely by the degree of wave turbulence. There is usually a belt of *Carpophyllum maschalocarpum* just below the *Carpophyllum angustifolium* fringe. *Lessonia variegata*, which is superficially similar to *Ecklonia radiata* but differs in having a divaricating stipe or stalk, occurs in the deeper part of the zone in areas with maximum wave-exposure. The oak-leaved kelp (*Landsburgia quercifolia*) also frequently occurs in areas of heavy wave exposure. Tolerant of a wide range of wave exposure is the smaller finely-branched *Carpophyllum plumosum*. There are several species of red algae including the agar weed *Pterocladia lucida,* and *Melanthalia abscissa*. The sea-urchin or kina (*Evechinus chloroticus*) is common in this habitat, usually nestled in holes, crevices and depressions. Here it often feeds on seaweed which has been torn off the rocks by heavy wave action. A wide variety of grazing molluscs also occurs in this habitat.

The photograph in Fig. 10, taken from a video drop clip, shows an example of shallow mixed weed habitat.

Urchin (kina) barrens (depth range 3-13 m)

This rocky habitat is characterised by a lack of large brown algae, the rock surface appearing bare and relatively barren. Upon close inspection nearly the whole rock surface is covered in a thin film of mauve to pink-coloured encrusting coralline seaweed (coralline ‘paint’), in some areas with coralline turfing algae as well. In a few areas small plants of the brown seaweeds *Carpophyllum angustifolium* or *Carpophyllum flexuosum* form patches within the predominantly coralline paint-covered rocks. The most conspicuous animal in this habitat is the sea urchin or kina which is often present at a density of 5-10 m^2 but may be much denser in places. It is the grazing by urchins that maintains the habitat in its relatively barren state. Sea urchins scrape the rock surface, removing recently settled algae and encrusting animals before they have a chance to grow. Sea urchins may also graze directly on large attached algae. This is relatively uncommon but when it does occur can lead to an extension of the kina grazed zone into formerly algal-covered areas. This zone is also the home of a number of small grazing molluscs, such as limpets and chitons. The most spectacular grazing mollusc here is the large Cook’s turban shell (*Cookia sulcata*), a rough surfaced gastropod 10 cm or more in diameter. The white anemone *Actinothoe albocincta* is often common here, particularly on steeper slopes in wave-exposed sites.

Kina barrens are more extensive and occur over a wider depth range in the exposed outer parts of Doubtless Bay. With increasing shelter the depth of occurrence and the depth range covered decreases, until in maximum shelter kina barrens are absent from the inner parts of Doubtless Bay. A similar pattern was observed in the Bay of Islands by Brook and Carlin (1992), and in the Hauraki Gulf by Grace (1983); it is further discussed by Choat and Schiel (1982), Walker (1999), and Shears and Babcock (2000).

An example of an urchin (kina) barren is shown in Fig. 11, taken from a video clip, which unfortunately does not show the kina very well.

Tangle-weed forest (depth range 1-5 m)

In the most sheltered areas of rock substrate, a thick, almost impenetrable tangled forest of the brown seaweed *Carpophyllum flexuosum* occurs. Individual plants may reach a height of over 3 m. With increasing wave exposure it intergrades with *Ecklonia* forest. This habitat usually gives way to *Carpophyllum maschalocarpum* and a narrow strip of the shallow mixed weed zone towards low tide. In a few sheltered areas in Doubtless Bay, *Carpophyllum flexuosum* is joined or in some cases replaced by the similar-looking *Sargassum sinclairii.* The seaweed and the rock substrate of this sheltered zone is nearly always covered with a thin layer of fine silt, settled out from the water, which may be relatively turbid. This detritus provides food for a range of specialized detritus and deposit feeders, such as the sea cucumber (*Stichopus mollis*) found on the rocks and in crevices beneath the weed canopy.

Fig. 12, taken from a video clip, shows the tangle-weed *Carpophyllum flexuosum* forest.

Ecklonia forest (depth range 4-29 m)

Ecklonia forest is characterised by dominance of the large brown laminarian kelp *Ecklonia radiata*. This seaweed attaches to the rock surface by a branched holdfast, and has a single cylindrical stalk or stipe, on top of which is a bushy top or lamina. The density of the plants varies considerably, with perhaps 5 m^2 plants in 'thin' beds, often in deeper water, and about 50 plants m^2 in dense, usually shallower, beds. The length of the stipe also varies, apparently with depth, from about 20 cm in adult plants in shallow slightly turbulent water, to about 80-100 cm in some deeper sites.

The canopy of the *Ecklonia* forest greatly reduces the light intensity on the rock surface beneath, which provides more favourable conditions for small encrusting animals such as bryozoans, hydroids, sponges and ascidians. The holdfasts of *Ecklonia* provide a crevice-like habitat for a rich diversity of life. In many areas the rocky bottom occupied by *Ecklonia* forest is of low relief, but where a high relief rocky substrate occurs within this zone, *Ecklonia* plants are usually found on the tops of the rocks, but not on their more shaded vertical sides, which typically are covered in a rich variety of encrusting animal life. As light levels diminish with increasing depth, sponges of numerous types become increasingly common within the thinning *Ecklonia* forest. Along reef edges where the *Ecklonia* forest drops on to a sandy substrate, there is often a fringe of the green seaweed *Caulerpa flexilis* on the rock immediately adjacent to the sand. It appears that *Caulerpa* is more capable of surviving periodic burial by sand and of colonising the more frequently disturbed sand/reef edge than *Ecklonia.*

The *Ecklonia* forest zone usually occupies the rocky reefs between the urchin barren zone and the sandy seafloor, generally in a depth range of 4-29 m. Targeted video drops allowed us to identify the transition zone where the lower boundary of the kina barren changed to the upper boundary of the *Ecklonia radiata* forest. This boundary was at 7-13 m depth, tending toward the deeper figure in increasing exposure, and was usually quite abrupt. Sometimes, particularly in relatively sheltered areas, the *Ecklonia* forest occurs adjacent to the shallow mixed weed zone, and may imperceptibly intergrade with it. A second habitat transition zone at about 29 m also was identified with video drop survey and diving. At this depth *Ecklonia radiata* forest weakened and thinned out while sponge and other encrusting invertebrate life became more diverse and abundant.

Fig. 13 shows an example of a fairly tall, sparse *Ecklonia* forest habitat, with some of the plants suffering dieback generally associated with old age. There are a few small plants growing beneath the old canopy.

Deep reef (depth greater than 29 m)

On the rocky bottom deeper than 29 m there is insufficient light to support the large brown seaweeds found in shallower water. Sponge species become the dominant life form on the deep reef. A massive grey sponge *Ancorina alata* is common, as well as the orange branching *Raspailia* sp. and purplish thin branching fingers of *Callyspongia ramosa*. Red cup sponges (*Stelleta hauraki*) and a wide variety of other large and small sponges are present. Soft corals (*Alcyonium* sp.) and pencil bryozoans (*Steganoporella neozelanica*) are also common. Small cup corals (*Monomyces rubrum*) also occur in this habitat. The deep reef habitat is most extensive on low-relief rock reef. In a few places, in particular around Albert Reef, Bastard Rock, and steep rock near Berghan Point and Knuckle Point, the rock bottom is more dissected and irregular, with frequent gullies and high rocks with elevations of over 3 m. These high-relief areas provide opportunities for an even greater variety of life than on the low-relief deep reef.

With the limited opportunities for exploring this habitat, we were unable to find any of the pink *Primnoides* gorgonian so common on deep reefs at Mimiwhangata (Kerr and Grace 2005).

Fig. 14 shows the deep reef habitat close to Knuckle Point, with sponges and encrusting invertebrates common on a steep rock wall.

Mixed sand and rock (depth range 0-29 m algal communities on patch reefs, and 29-40 m sponge encrusting invertebrate communities on patch reefs)

This habitat type occurs in transition zones between reef and sediment as well as in areas comprised of a patchy mixture of rock and sediment habitats. It is very extensive through the middle areas of Doubtless Bay, and also common around the fringes of reefs to the north and east of the Bay. This ecologically important habitat is the preferred habitat of some species and is part of the habitat of the juvenile life stage of some reef species (for example, goatfish, juvenile snapper and blue cod). It is usually the place where foraging by species that shelter on reefs but feed in the sediments (like rock lobsters) is most intense. The habitat covers those areas where there is a mixture of small patches of rock scattered amongst sandy areas, but each is of such small extent that it is not possible to map them on the scale used or with the degree of precision of this survey. Areas of mixed sand and rock occur most commonly where a gently shelving rocky substrate meets a flat sandy bottom. If the rock surface is dissected by crevices and gullies sand fills these gullies as the rock dips beneath the sand surface. At depths less than 29 m there may be sand and or gravels combined with a shallow mixed weed zone, a kina grazed zone, or *Ecklonia* forest. Several species of red algae can be common in this mixed habitat, sometimes including large plants of *Gigartina circumcincta.*

The green sea rimu (*Caulerpa flexilis*) forms extensive beds where low relief rock is covered with a thin layer of sediment, or where sediment frequently comes and goes over the rock surface. It also often forms a fringe around patch reefs occupied by *Ecklonia* forest. '*Caulerpa* mats' have been elevated to a separate habitat type by Shears et al. (2004), but at the scales we are working with for this study it is not possible to map them separately.

At depths greater than 29 m sponges and other encrusting invertebrates dominate the rock habitat adjacent to soft sediments.

An example of mixed sand and rock, at the depth of the shallow mixed weed zone, is shown in Fig. 15.

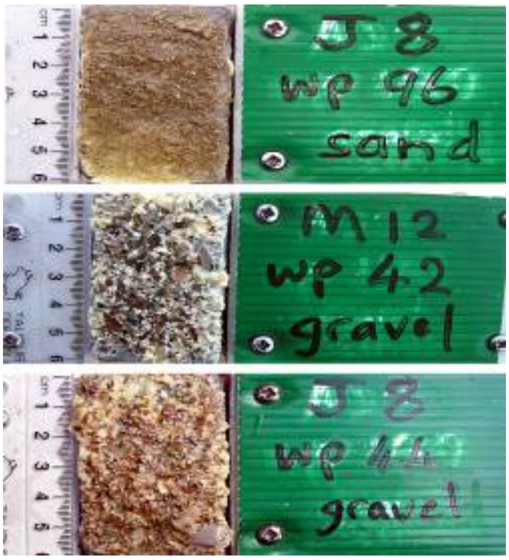


Fig. 5. One sample of sand and two of gravel collected with the rapid sediment sampler.

Fig. 6. The drop-video apparatus being lowered over the side of the 4.2m Mac boat.

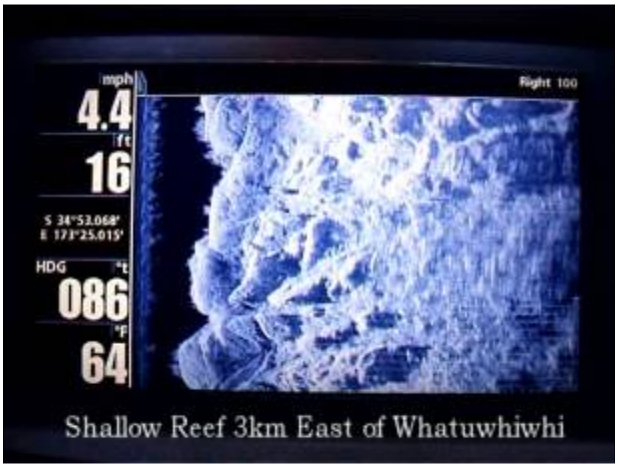


Fig. 7. Single-sided sidescan image of shallow high-relief rock.

Fig. 8. Double-sided sidescan image running from sand at the bottom to low relief rock toward the top.

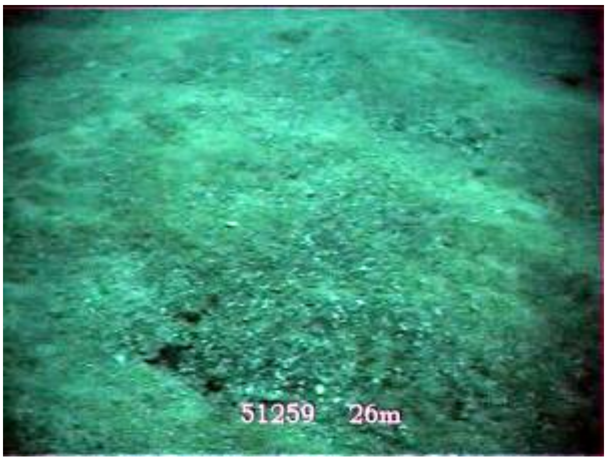


Fig. 9. Gravel bottom with ripples

Fig. 10. Shallow mixed weed zone

Fig. 11. Urchin (kina) barrens zone

Fig. 12. Tangle-weed forest

Fig. 13. *Ecklonia* forest at moderate depth, showing some die-back and young plants under the canopy.

Fig. 14. The Deep reef zone near Knuckle Point, showing a yellow finger sponge, grey rambling *Ancorina* sponge, pencil bryozoans, encrusting sponges, and a feather star emerging from the grey sponge.

Fig. 15. Mixed shallow mixed weed zone and sediment.

Fig. 16. Large quantities of dry (left) and fresh (right) red weed rotting on Tokerau Beach.

Reference sites at scale of 1:5,000

The following discussions refer to the detailed habitat maps on A3 sheets folded and bound into the report toward the back. Each map and its accompanying aerial photo montage can be folded out for reference while reading the written discussions. The location of each map is indicated on Fig. 4 map.

1. Brodie's Creek

This site covers an embayment on the northwest coast of Doubtless Bay, about half way from Whatuwhiwhi to Knuckle Point. The shoreline is relatively sheltered compared with other parts of this coastline. The site includes the only estuary in the mapped area of Doubtless Bay. This very small estuary is a microcosm of larger estuaries, and includes the upper estuary with stream, salt marsh, mangrove forest, sand flats with cockles, sheltered rocky shores with oysters, a cobbly area with extensive necklace weed, a gravelly entrance channel, and a sand bank beside the entrance with a small bed of pipis.

Outside the estuary the coastline to the east is fairly sheltered, the rocky shore dropping fairly quickly through shallow mixed weed and mixed *Ecklonia* and sediment to a sandy bottom. The *Ecklonia* forest here has moderate numbers of tall tangle-weed plants scattered through it. Further east again, *Ecklonia* forest with tangle-weed drops to mixed *Ecklonia* forest and sediment extending farther offshore, eventually reaching sufficient depth for a fringe of deep reef and sediment before dropping to a gravel bottom.

To the west of the estuary is a small sandy beach. The rocky shore further west is relatively wave-exposed and quite complex with many reefs and rocks separated from the mainland. A couple of gravelly beaches back the exposed rocky shore in small embayments. Sub-tidally, shallow mixed weed passes to well-developed kina barrens, then mixed *Ecklonia* forest and sediment, before reaching fine sand out in the middle of the bay.

2. Whatuwhiwhi

Further west the rocky shore continues to be fairly wave-exposed due to its southeasterly aspect. A rugged rocky shore is backed by a couple of narrow sand beaches. The rock platform contains numerous rock pools, some of them quite large. Isolated rocks immediately offshore are common, and an extensive reef system extends to the south. Large areas of shallow mixed weed are broken up by narrow gutters and gullies amongst the complex rock outcrops of the reef.

Well-developed kina barrens lie seawards of the shallow mixed weed fringing the exposed rocks. In much of the area especially to the west the kina barrens are mixed with sediment patches. Further south large areas of *Ecklonia* forest occur, some as solid forest, but even bigger areas with a complex mixture of sediment and rock supporting *Ecklonia* on the outcrops. Fringing much of the rock/sediment interface, small areas of *Caulerpa* sea rimu are widespread. Adjacent to the rocks are two large areas of gravel, with a high density of the morning star shell (*Tawera spissa*) and a few associated shellfish species. To the southwest are extensive sand flats.

3. Parakerake

Further west the shores are moderately sheltered and in most places drop quickly from intertidal rocks to shallow sand. Several sheltered sandy beaches are present. Immediately adjacent to two of the beaches are areas of small rocks or cobbles just below low tide. The shallow mixed weed zone is mostly fairly narrow and drops straight on to sand. In the lee of a headland small areas of tangle-weed forest occur in the most sheltered spots. A small island a few hundred metres offshore has a small area of kina barren on its north side, but mostly this area is too sheltered for kina barrens to be well developed. A series of small subtidal reefs form a chain from the island to the mainland, each with its own oasis of shallow mixed weed.

South of the island and rocky shores, the sandy seabed is relatively flat. Visible in the aerial photo is a series of elongated dark patches of gravel (more clearly visible in the cover photo), apparently streaked out in rows by the prevailing wave attack from the east. The gravel patches probably move during storm events.

4. Aurere

At the southern end of Tokerau Beach is Aurere, a small estuary with a sandy entrance and mangroves further upstream. The estuary itself was not investigated. The area mapped is all quite shallow and features an island and reefs sheltering a small lagoon almost enclosed at low tide. The lagoon is mostly sandy, but contains numerous rocks with tangle-weed forest in the sheltered waters.

The island is connected to the mainland by a gravelly tombolo covered at high tide but partly exposed at low tide. An area of gravel also fringes the sandy beach south of the lagoon.

Off the mouth of the estuary and towards the gravelly tombolo are numerous small isolated rocks, some of which are exposed at low tide. Many of these support numbers of the green-lipped mussel *Perna canaliculus.*

To the north of the island and moderately exposed rocky shore, a fringe of shallow mixed weed drops quickly on to the sandy seafloor. A short distance offshore is an isolated reef, with shallow mixed weed surrounding it in the shallows, but this drops straight into *Ecklonia* forest then on to the sand.

Toward the eastern end of the mapped area is a small sheltered rocky cove with a gravelly beach at its head. Rocks scattered throughout this cove are covered in the plumose seaweed *Carpophyllum plumosum.*

5. Chuck's Cove

Between Cable Bay and Coopers Beach is a complex rocky shore backed by low cliffs and a few gravelly beaches. A small cove, Chuck's Cove, is almost enclosed at low tide. Sand in the cove is fringed by gravelly areas. Off the eastern end of the Cove is a tiny estuary with some very large mangrove trees. Mangroves are also scattered over the gravelly shore east of the Cove, as well as a few plants to the west in pockets of sediment on what is essentially a rocky shore. This is a very unusual occurrence of mangroves.

The moderately exposed rock shores continue into an extensive area of shallow mixed weed, which drops abruptly on to the shallow sandy seabed. Offshore is a series of reefs and an island, with fringes of shallow mixed weed changing straight into *Ecklonia* forest. Some areas of gravel are associated with the reefs and island.

The water in this area was rather turbid at the time of our survey, and the aerial photos we obtained showed very little detail below the water.

6. Onete

On the eastern side of Doubtless Bay, a double embayment at Onete marks the change from exposure to shelter along the Berghan Point coast. North of Onete the rocky shore is exposed to northerly storms, whereas Onete itself and further south is in moderate shelter.

North of Onete the complex rocky shore is backed by cliffs, with a couple of sea caves on the point north of the bay. A narrow fringe of shallow mixed weed drops quickly into extensive kina barrens, then *Ecklonia* forest merging into gravelly sand.

The double embayment features two gravelly beaches giving way to sand just below low tide. Further south the moderately sheltered rocky shore is fringed by a narrow band of shallow mixed weed, and a narrow kina barren only present in small areas decreasing further south with increasing shelter. The mixed *Ecklonia* forest and sediment to seaward has scattered plants of the tangle-weed *Carpophyllum flexuosum* standing tall from the *Ecklonia* canopy, further indicating increasing shelter southwards. The rocky reef soon gives way to a sandy bottom. Towards the southern end of this reference site is another gravelly beach, also dropping quickly on to sand at low tide.

7. Fairway Reef

Fairway Reef is one of two reef systems which have rocks exposed at the surface in Doubtless Bay. The other is Albert Rocks, further offshore.

Fairway Reef is a large area of shallow rock with two high spots exposed at low tide and dangerously awash at high tide. An area of shallow mixed weed surrounds the exposed rocks, but additional areas of the same habitat occur on other shallow rock areas nearby. These are all surrounded by a huge expanse of kina barren on an extensive shallow rock platform. An irregular area of sand occurs in a shallow depression near the centre of the reef.

Particularly around the western end of the reef, the kina barrens drop steeply and abruptly into *Ecklonia* forest. The rocky bottom is extensive in all directions except toward the southwest, where gravel is encountered only a few hundred meters from the emergent rocks. Otherwise the low relief reef is mixed with areas of sand, with *Ecklonia* growing on the rocks where possible. The sea rimu *Caulerpa flexilis* seems to thrive where low rock is frequently covered by a thin layer of sand. In some areas of mixed rock and sand, several species of red seaweeds are seasonally prominent.

Discussion

The habitat maps of Doubtless Bay produced in this study are intended as tools for managers, iwi and community groups discussing options about marine protection, and as a baseline for studies of change over time. The surveys, aerial photographs and habitat maps provide a unique opportunity to assess changes occurring over a long period into the future.

In the current survey we had the opportunity to adapt a range of modern habitat mapping methods which enabled us to work efficiently over the depth range studied throughout Doubtless Bay. We were also able to explore the practicalities of how the various techniques could be used in combination to gather the most information for the least effort. In pragmatic terms this is a significant factor when attempting to map habitats at this scale. The combined use of GIS and GPS has created many advantages and opportunities for the future. Having the ability to georeference all data and photos and then arrange them in various 'layers' greatly enhanced our ability to interpret the data. The GIS layers can be spatially analysed and used for future research, greatly increasing the value of the habitat maps.

Limitations of this study

There were some limitations to our methods which should be noted. The precision changed with depth, reflecting the methods used, being greatest in shallow areas and decreasing as the depth increased. We suggest this is appropriate in that significant biological boundaries occur across much smaller scales in shallow waters and tend to become further apart as depth increases

Areas not on the sonar swathes or tracks, deeper than 15 m and/or not observed in video drops or dives or by snorkelling are interpretations or approximations between known points or areas. In offshore areas habitat variation between the observations is unknown and can only be determined by 100 % survey cover (e.g. side-scan or multibeam sonar). However, given the broad scale of the main habitat features documented here, we expect these variations will not be major. Our methodology also involved subjective judgments regarding which habitat descriptor (or class) 'best described' the sonar or video image of the area we were observing. This necessarily reduces the level of habitat patchiness that can be represented in the habitat map.

In depths less than 15 m the accuracy of the mapping was determined by the interpretation of aerial photography which in most areas afforded resolution of detail down to 3-5 m, however overall accuracy was limited by georeferencing error (i.e. approx 10-15 m).

Mixed reef and sediment areas

A special feature of Doubtless Bay is the extensive area of seabed characterised by mixed sediment and rock at a range of depths. Mostly these areas are of fairly low relief, and often a mix of exposed bedrock and loose rocks in a matrix of sand or gravel sediment. The firm rock substrate is occupied by either kina barrens, patchy *Ecklonia* forest often with sea rimu *Caulerpa flexilis*, or sponges and encrusting life of the deep reef. Together these mixed reef and sediment areas constitute 17.82% of the mapped area.

Low relief mixed rock and sediment areas such as this are likely to be important habitats for juvenile fishes of a number of species. The prevalence of this habitat in such abundance in Doubtless Bay appears to be an unusual and special feature.

Deep reefs

Deep reef areas characterised by sponges and encrusting life are far less prevalent at Doubtless Bay (only 0.58%) than at Mimiwhangata (over 30%). There is not much rocky substrate at the required depth in Doubtless Bay - simply an accident of geology and geography. At Doubtless Bay there is also a lack of the extensive beds of pink *Primnoides* gorgonians which are a feature of the Mimiwhangata deep reefs.

Soft sediments

Our limited observations of the sediment areas of Doubtless Bay indicate that there is a high degree of variation in types of sediment present. The sediments are likely to be occupied by a similar variation in benthic associations of species characteristic of the different sediment types and depths.

Sediments out off Tokerau Beach appear to be characterised by sands with streaky patches of gravel of limited extent, which probably shift around in stormy conditions. Extensive areas of gravel occur in deeper water, and in the deepest parts of the bay firm muddy sands predominate.

Mapping of these soft sediment benthic communities would no doubt add significantly to knowledge of the biodiversity of the Bay.

Information gaps

Currently the largest information gap relates to sediment-dwelling life in Doubtless Bay. As mentioned above, mapping of the soft sediment benthic communities would add greatly to our knowledge.

Due to limited field time we were unable to carry out as much ground-truthing by diving, snorkelling or video drops as would be desirable. Further exploration would be valuable to better refine habitat interpretations. This would be particularly useful in some of the mixed reef and sediment areas extensive throughout the Bay, as well as on the limited areas of deep reef habitat in the outer Bay.

We were told of some low reef structures off Tokerau Beach (Ramp Road area) but were unable to explore to ascertain their existence or nature.

Historically there have apparently been beds of scallops and horse mussels off Tokerau Beach, but we have been unable to explore for these also. Some targeted manta board runs would be useful for this purpose.

Due to patchy cloud cover during aerial photography, there were gaps in our coverage. The main gaps were parts of the Berghan Point coast, coast between Coopers Beach and Taipa, and Fairway Reef. Desirable additions would be the area off Ramp Road to determine the existence of shallow rock reefs, Coopers Beach and offshore reefs and islands, and from Coopers Beach to Hihi Beach during conditions with clearer water. In clear water conditions it may be possible to photograph some reef detail on the shallower reef areas near the middle of the Bay.

During our visit in autumn there was a huge wash-up of red seaweed on the northern end of Tokerau Beach (Fig. 16), which produced offensive smells as it rotted on the upper beach. It also caused anaerobic conditions in shallow water offshore as it drifted in deep swathes in a couple of metres of water prior to coming ashore, leading to deaths and wash-ups of considerable numbers of shallow water shellfish off the beach. (See dark drifts of weed close to the beaches in the northwestern corner of the aerial photo montage for Parakerake. The weed was much more extensive than this off Tokerau Beach when it was causing a problem.) We were not able to determine the species or where the seaweed lives offshore. Serious wash-ups of this weed have apparently become a regular occurrence in late summer over several recent years. Identification of this weed and determination of where it lives (possibly on shallow reefs offshore) would be a prerequisite to assessing the likely cause of the problem and seeking a solution.

Conclusions

1. Marine habitats of Doubtless Bay are typical of those occurring generally on the Northland east coast.

2. The large area of low-relief reef, and mixed reef and sediment, throughout the central area of the Bay is unusual and appears to be a special feature of Doubtless Bay. These habitats have a high degree of small-scale surface irregularity which may impart special value as a nursery area for several fish species.

3. The great variety of coastlines, with different shore structures, depths nearby, and degrees of wave exposure, makes Doubtless Bay an excellent area for learning about the effects of shore type and exposure on marine ecology.

4. The extensive development of urchin (kina) barrens, particularly on Fairway Reef and close to the moderately exposed shorelines on the northwest and southeast sides of the Bay, suggest that kina predators, particularly snapper and crayfish, have been seriously depleted.

5. There are many opportunities, and several prime target areas, for establishment of Marine Protected Areas (MPAs) in the Bay, which would go a long way toward promoting the recovery of depleted snapper and crayfish stocks and restoration of habitats impacted by heavy fishing pressure. They would also have an educational role not only for schools but also for the wider community.

6. The habitat maps produced in this report will help promote understanding of marine aspects of the Bay, and discussion within the community of options for better management of marine resources in Doubtless Bay.

Recommendations

1. The information and maps in this report should be used widely in the Doubtless Bay area, to promote an awareness within the community of the values and attributes of the marine aspects of the Bay.

2. The report and maps should be used to promote discussion within the community of future directions and options for marine management of the Bay, including establishment of MPAs and Marine Reserves as the central core of any restoration and ongoing maintenance programme.

3. Refinement of an understanding of some of the habitats in the Bay would be desirable, including acquisition of much better images of the various habitats to help with presentations and other work within the community.

4. Moves should be made to fill the key information gaps identified, particularly soft sediment faunas, better habitat interpretations, underwater photos, aerial photos, and an understanding of the red algal washup problem at northern Tokerau.

5. The opportunity exists to establish a few key sites where formal monitoring could commence, perhaps involving members of the local community in an on-going programme.

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