C036-AH-REP-0121

# INPEX Ichthys Project

## Benthic Habitat Mapping of the Darwin Region:

## Methods of data collection, collation and map production

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# 1. Introduction

Geo Oceans (GO) was commissioned to collate and classify available marine habitat data of the seafloor (benthic) substrates and biological communities to produce maps showing the distribution of sediment particle size and the benthic habitats in the waters surrounding the Darwin Harbour region. INPEX has also conducted additional studies of the benthic environment of Darwin Harbour, Gunn Reef and the inshore waters from Fannie Bay to Adam Bay. These studies included qualitative and quantitative subtidal and intertidal surveys of the hard coral, macroalgae, filter-feeder and seagrass communities on the reef and sediment substrates. The data collected during these additional studies was collated with the existing habitat data to improve the resolution and accuracy of the existing benthic habitat maps. The habitat maps provide a tool to quantify the spatial distribution of the biological communities and substrates found in the Darwin region. The data will be used to facilitate environmental management decisions for the proposed INPEX Ichthys Gas Field Development project.

To collate data from different data sources all of the data must be classified to the same classification scheme using consistent decision rules and classification definitions for all data sources. This report outlines the decision rules applied to reclassify the existing data and the processes used to display the spatial distributions of the habitats and describe the data collection methods used during the additional surveys including intertidal surveys and subtidal diving surveys.

# 2. Data collection methods

## 2.1. Towed video survey

Towed camera transects were used to collect data to classify the benthic habitats in the study area of the greater Darwin Harbour region. The data collected during this survey was combined with existing habitat data to update the benthic habitat maps. The equipment and data collection methods are described below.

### 2.1.1. Field sampling

The study area included the near-shore waters from Fanny Bay to Adam Bay and East Arm in Darwin Harbour. The field survey was conducted over 7 days of field operations from 29$^{th}$ November to 5th December 2010 aboard the vessel 'MV Mystified', a 17.5m long vessel with a draft of 1.4m.

The sampling plan was designed to maximise the available field time by choosing an optimal transect length and transect line spacing, considering the surrounding habitat type. In areas of complex habitat or areas of particular interest (e.g. Fannie Bay) the video transect lines were spaced 200m apart. In areas of homogeneous habitat (e.g. Shoal Bay) the transect lines were spaced up to 500m apart. The transect length was at least 30m long but in areas of sparse, patchy habitat the transect length was increased to at least 50m long. Areas of particular interest (e.g. seagrass meadows and reef habitats) were surveyed more intensively to determine habitat boundaries and community composition.

The transects involved towing a video camera along the seafloor at a speed of 1 to 2 kilometres per hour (km/h$^{-1}$) and approximately 1 metre (m) above the substratum.

### 2.1.2. Video transects

The field survey recorded 408 video transects (of varying lengths) covering a total distance of approximately 20 km using a standard definition video system. The video frame covers approximately a 0.5m wide band of substrate (at 1m above substratum), resulting in an area approximately 10,000 km$^2$ of benthic habitat surveyed. The video data analysis produced approximately 36,000 rows of habitat point data within the survey area.

### 2.1.3. Towed video system

The camera was mounted to the sled on a 45$^o$ angle pointing forward. The video camera was a high resolution (640x480 lines), low light camera (0.1 lux), standard definition video camera with a wide-angle lens. Video footage was encoded with latitude and longitude coordinates using a Furuno GP-37 differential global positioning system (DGPS), which has an accuracy of 5 m (95% of the time). The GPS locations were encoded to the audio and video tracks of the video footage. The video footage was recorded to an Archos 5 internet tablet hard disk drive recorder in MPEG-4 AVI format with VGA resolution (640x480) at 30 fps. Frame grabs from the video footage are displayed in Figures 1, 2, 3, 4 and 5.

The camera system consisted of a small, lightweight, underwater video camera system mounted in a sled/housing that has a hydrodynamic design to minimise the friction and drag forces from the water, thereby reducing the distance that the camera tows behind the vessel. Because the study area was in shallow waters, a distance correction (to allow for the difference between the video camera and the GPS location) was not required. The estimated distance of the camera in relation to the GPS antennae for the depth classes (listed) was as follows:

- 0 to 5m water depth – camera distance = 0m
- 5 to 10m water depth – camera distance = 10m
- >10m water depth – camera distance = 20m

#### 2.1.4. Video data analysis and habitat classification

The video footage was analysed in real time in the field, by a marine scientist trained and experienced in video analysis and habitat classification. A custom designed Visual Basic software program was used which allows the user to assign biota and substrate attributes to GPS position in a spreadsheet while the video is recorded. The habitats were classified according to the INPEX habitat classification scheme (Appendix 1 and Appendix 2).

Qualitative estimates of the cover of the different biological community and substrate types were made using density classes listed in Appendix 1 and Appendix 2. Substrate type and particle sizes were based on the Wentworth grade scale of particle sizes: particles greater than 64 mm (cobble) are defined as consolidated (reef); substrate and particles smaller than 64 mm (pebble) are defined as unconsolidated (sand) substrate. For poor quality video footage where the substrate type was difficult to see, the substrate type was classified based on the surrounding substrate or what was likely to occur. The presence of specific biota types in each biota class was recorded, with the level of taxonomic detail being limited by the quality of the video footage, which in turn is dependent on the environmental conditions (e.g. water visibility and sea state) and the speed at which the towed video is collected. For this survey, the video was analysed to seagrass genera and macroalgae, filter-feeders, hard corals and soft corals to morphological life-form level. Some biota could be identified to genus or species level as listed in Appendix 1. However, this data is only indicative and is dependant on image quality and should not be used for presence/absence analysis to this taxonomic level.


- **Figure 1 Left: Hard coral (*Acropora* sp.) at Old Man Rock; Right: Hard coral (*Turbinaria* sp. ) at Lee Point**


- **Figure 2 Left: Macroalgae (*Halimeda* sp.) near East Point; Right: Macroalgae (*Sargassum* sp.) at Lee Point**


- **Figure 3 Left: Seagrass (*Halodule* sp.) in Fannie Bay; Right: Seagrass (*Halophila* sp.) in Fannie Bay**


- **Figure 4 Left: Filter feeding soft coral (Gorgonian fan) at Lee Point; Right: Sponge and sea whips at East Point**


- **Figure 5 Left: Medium bio-turbation in mud sediment; Right: Sand sediment**

### 2.1.5. Quality assurance and quality control

The video analysis data was imported into a Microsoft Access database to perform error checking and quality control queries before undertaking analysis and presentation in a GIS package. The video footage was checked for erroneous or unusual data. If necessary, the video footage was re-analysed using the same methods as used during the field survey, and a GPS decoder was used to export the GPS position of the video footage collection location as the video is played-back.

### 2.1.6. Bathymetry

Bathymetry (depth) data was captured during the video field survey using a Garmin Intelliducer eco-sounder. The Intelliducer received depth data up to a vessel speed of approximately 12kn. The accuracy of the Intelliducer is within 10cm in a water depth between 0-10m and 1m in water depth of >10m. The depth data collected during this survey is of sufficient accuracy for the purposes of this survey.

Note, however that this bathymetry data is not of sufficient accuracy to be used where high accuracy bathymetry data is required (e.g. engineering design etc) or for vessel / shipping navigation purposes.

### 2.1.7. Depth correction for tide

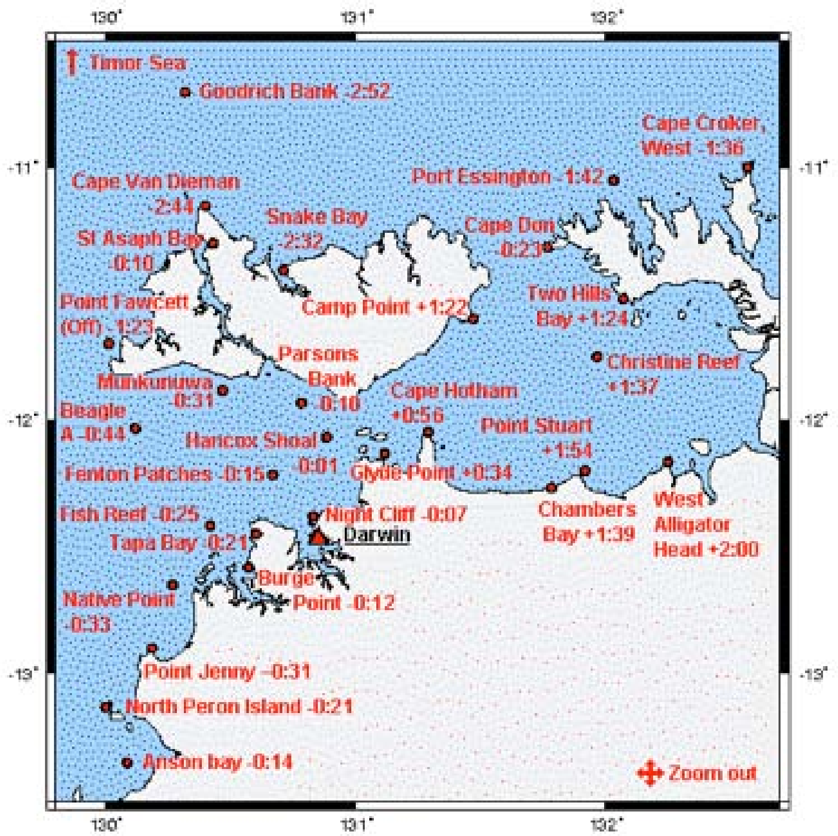
Depth was recorded throughout the day during the period 29/11/2010 to 5/12/2010, at tide heights ranging from 0.76 to 6.97 metres above lowest astronomical tide, the datum used in this region (Figure 6) and to which the bathymetry data produced for this project has been referenced. The depths were corrected for tide using a method based closely on the 'Rule of Twelfths', a tool commonly used in yachting to adjust depth for tides (see http://en.wikipedia.org/wiki/Rule_of_twelfths).

This rule assumes that the rate of flow of a tide increases smoothly to a maximum halfway between high and low tide before smoothly decreasing to zero again and that the interval between low and high tides is approximately six hours. The rule states that in the first hour after low tide the water level will rise by one twelfth of the range, in the second hour two twelfths, and so on according to the sequence - 1:2:3:3:2:1. The rule, as generally applied, assumes that the period between high and low tides is six hours. For this project, the period varied between 5.3 and 7.2 hours. To improve accuracy, the rule was modified such that the water level is assumed to rise by one twelfth of the range during the first one sixth of the period between tides (approximately an hour), rather than during the first hour (precisely), and similarly for the remaining five sixths of the period between tides.

There are three tide stations relevant to the study area. The tide times from the standard tide station at Darwin were used to correct depths from Fannie Bay southwards, while the secondary stations at Night Cliff (approximately 7 minutes behind Darwin) and Glyde Point (approximately 34 minutes ahead of Darwin) were used to correct data from Shoal Bay and Adam Bay respectively. This approach was confirmed with HR Wallingford, the primary end user of the data (pers. comm., Stephen Richardson, 4 January 2011).

In addition, a further offset of 0.5 m, consistent across the entire dataset, was added to the depth to account for the depth of the transceiver below the water.

The rule of twelfths and transceiver depth corrections were calculated using a custom VBA Excel Macro.

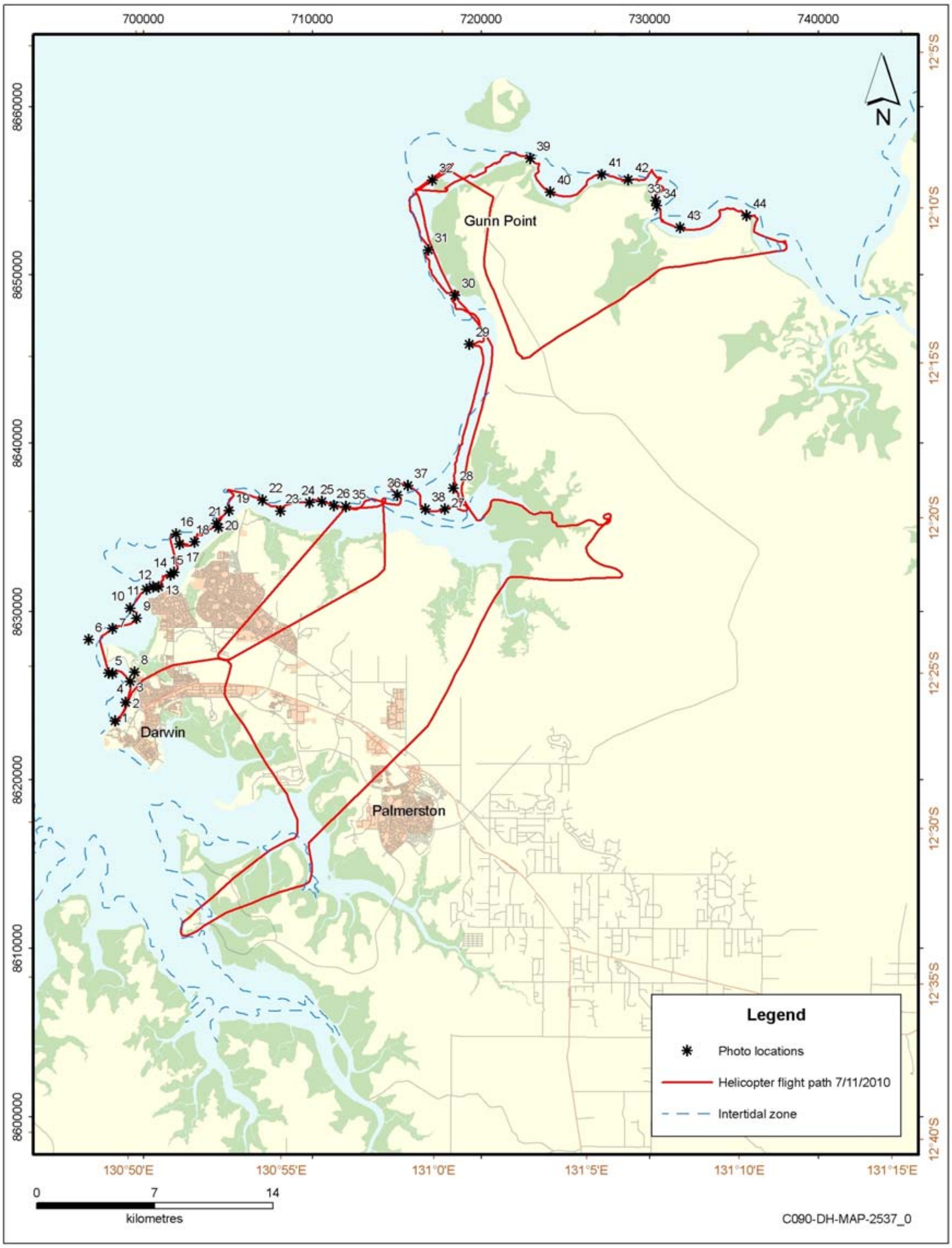



- **Figure 6. Tidal stations near Darwin Harbour**
  **Source: Commonwealth of Australia 2011, Bureau of Meteorology**

## 2.2. Intertidal survey

The distribution of benthic habitats in the intertidal area between Lee Point and Fannie Bay and the East Arm of Darwin Harbour was mapped using low tide aerial imagery sourced from the NT Government. The habitat boundaries between reef and sediment substrate identified in the imagery were manually digitised in Arc Map 9.3 at a scale of approximately 1:10,000.

The digitised habitats were classified for biological community type using intertidal habitat point data collected from an aerial survey using a helicopter during spring low tide on 7th November 2010. The aerial survey collected geo-referenced high-resolution still images and high definition video footage along the flight path displayed in Figure 7. The still images were analysed using visual estimates of biological community type and percent cover and classified according to the INPEX habitat classification scheme (Appendix 1) to produce known habitat point data. The point data was used to classify the reef substrates identified from the digitised aerial images, assuming that the data classified from the still images represented the biological communities in that habitat.




- **Figure 7 Helicopter flight path and photo locations from the intertidal aerial survey**

### 2.3. Walker shoal dive survey

#### 2.3.1. Data collection method summary

On 29 and 30 November 2010, URS Australia Pty Ltd (URS) undertook surveys by diver of selected hard substrate communities at five sites within Darwin Harbour (Table 1). The survey activities were undertaken by suitably qualified and experienced commercially-certified scientific divers from URS, with diving support provided by Tek Diving Services.

- **Table 1 Dive survey locations**

| DATE | LOCATION | LATITUDE | LONGITUDE |
|---|---|---|---|
| 29/11/10 | Walker Shoal | 12° 29.463' S | 130° 52.381' S |
| 29/11/10 | Dudley Pt Bommies | 12° 25.074' S | 130° 48.932' S |
| 30/11/10 | Stevens Rock | 12° 29.160' S | 130° 47.114' S |
| 30/11/10 | Plater Rock ('Pinnacles') | 12° 28.579' S | 130° 47.207' S |
| 30/11/10 | Kurumba Shoal | 12° 28.319' S | 130° 47.189' S |

The aim of the survey was to characterise the benthic filter feeder community on Walker Shoal and to compare it against the communities present on hard substrates, at similar depth, in other parts of the harbour that are outside the areas predicted for impact from dredging or spoil disposal (i.e. Stevens Rock, Plater Rock and Kurumba Shoal). Dudley Point Bommies site was visited to enable a qualitative description to be made of the predominant taxa present within the hard coral community at that location.

Health and safety considerations dictated the use of video transects, rather than line intercept transects, for analysis of the benthic communities. Whilst the relatively shallow depths did not restrict dive times, the periods within which the surveys could be conducted were limited to those times when tidal currents were sufficiently low (strong currents were experienced, even though the survey was conducted during a neap tide period).The greater speed with which video transects are recorded also reduced the exposure time of the divers to other hazards, such as dangerous marine fauna (i.e. crocodiles, sharks, jellyfish, stonefish).

Four 20 m long transects were laid at a depth of 7 m below LAT. The start of each transect was separated from the end of the previous transect by distances of some 2-5 m. A video camera was held vertically a distance of 0.5 m above the substrate, giving a field of view some 0.5 m wide, hence each video record captured the benthic community present on an area of approximately 10 m2. These video records will be analysed to provide quantitative estimates of cover and diversity of the benthic community. At Stevens Rock, Plater Rock and Kurumba Shoal, three 20 m long transects were laid at depths of 7 m below LAT. The same transect spacing and video techniques used at Walker Shoal were applied at these three locations.

At each location a collection was made of the dominant taxa, adhering to the requirements of a collecting permit issued under the NT Fisheries Act. Samples of the biota were removed, transferred into calico bags aboard the dive support vessel and placed on ice. On shore, the samples were catalogued, photographed, labelled, preserved in 70% ethanol and transferred to the Museum and Art Galleries of the Northern Territory, from where they will be distributed for taxonomic identification.

At Walker Shoal, an initial diver inspection was undertaken to ascertain the variation (with depth) of the abundance and diversity of taxa within the filter feeder community. At the bottom of the shoal (around 11 m below LAT), benthic cover was quite low (<10%); this generally increased with shallowing water depth, up to around 25% cover at 7 m below LAT. The surface of the shoal was rugged (up to 0.5-1.0 m relief) and the distribution of the benthic communities was very patchy, in terms of both benthic cover and diversity of taxa. 7 m below LAT was selected as a suitable depth at which to lay transects for the collection of video records, as the benthic community at this depth appeared to be comprised of the dominant taxa present in the higher-cover areas of the shoal.

### 2.3.2. Data classification method for habitat mapping

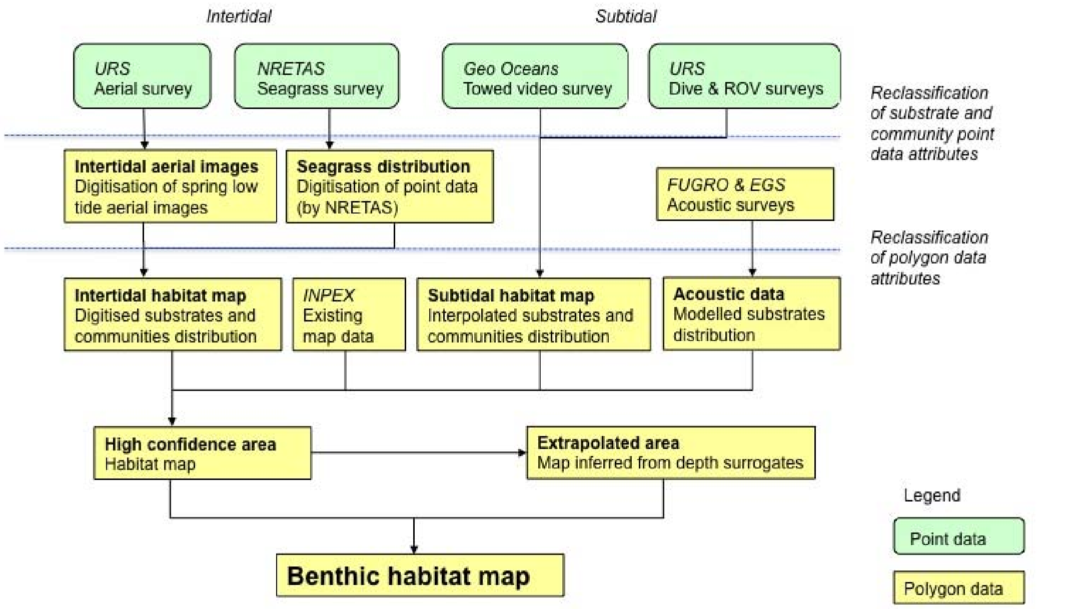
The URS diver and ROV surveys (including the survey discussed in section 2.3.1) used quantitative analysis methods to quantify the percent cover of the biological communities to detect temporal and spatial variability at the survey locations. This data included detailed taxonomic identification (e.g. identified to species or genus level). The field personnel and image analyst also recorded a qualitative description of the biological community composition and percent cover to describe the benthic habitat type at each survey location. The qualitative assessment description was re-classified into the INPEX habitat classification scheme (Appendix 1) and was used to classify the survey point location. This point data was collated into the total known-point data set (Section 3.3) and was used for the habitat map production.

# 3. Data collation methods

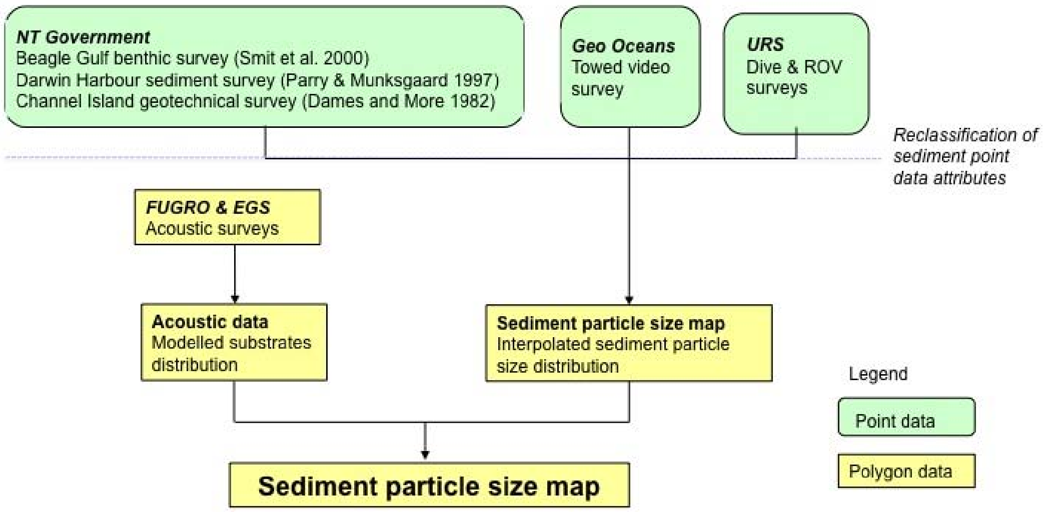
All of the available habitat data in the Darwin region was collated to produce a total known dataset consisting of point and distribution (polygon) data. The data collated into the known dataset was collected using both quantitative and qualitative survey methods across different spatial and temporal scales with varying accuracy. The known dataset consisted of substrate and habitat data that were used to define and classify the habitat composition and distribution. The datasets were classified and collated to produce sediment particle size and benthic habitat maps. The process of data classification and processing to produce the sediment particle size and benthic habitat maps are illustrated in the flow diagrams in Figure 8 and Figure 9. The following sections provide a description of the methods used for each step of classification for each of the data sources.

## 3.1. Habitat classification

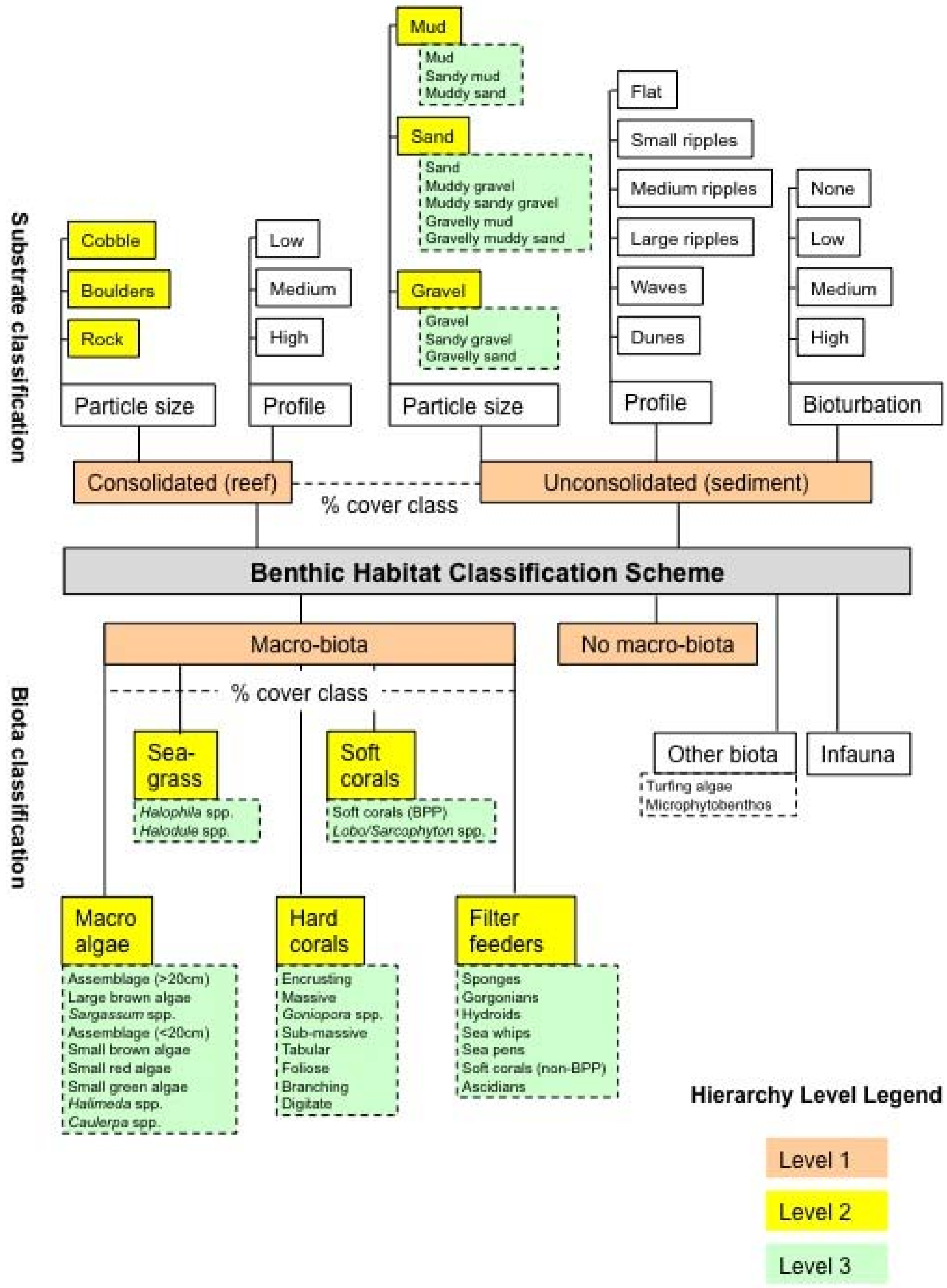
To combine the data from the different data sources the INPEX habitat classification scheme was used to reclassify the total point dataset using consistent decision rules and classification definitions. This allows data collected with different levels of detail to be combined to produce substrate and community distribution maps at different scales. The classification scheme is a hierarchical classification scheme that groups low-level classes into broader high-level classes (Figure 10), allowing fine scale data (i.e. quantitative data) to be combined with broad scale data (e.g. qualitative data). The classification scheme was adapted from a national intertidal and subtidal benthic habitat classification scheme (Mount et al., 2007) and was developed in consultation with NRETAS. The decision rules and habitat and substrate classification definitions are provided in Appendix 1 and Appendix 2.




- **Figure 8 Schematic of the habitat data collation and the benthic habitat map production process**




- **Figure 9 The data collation process used to produce the sediment particle size map.**




- **Figure 10 Habitat classification scheme hierarchical flow chart**

### 3.2. Point data classification

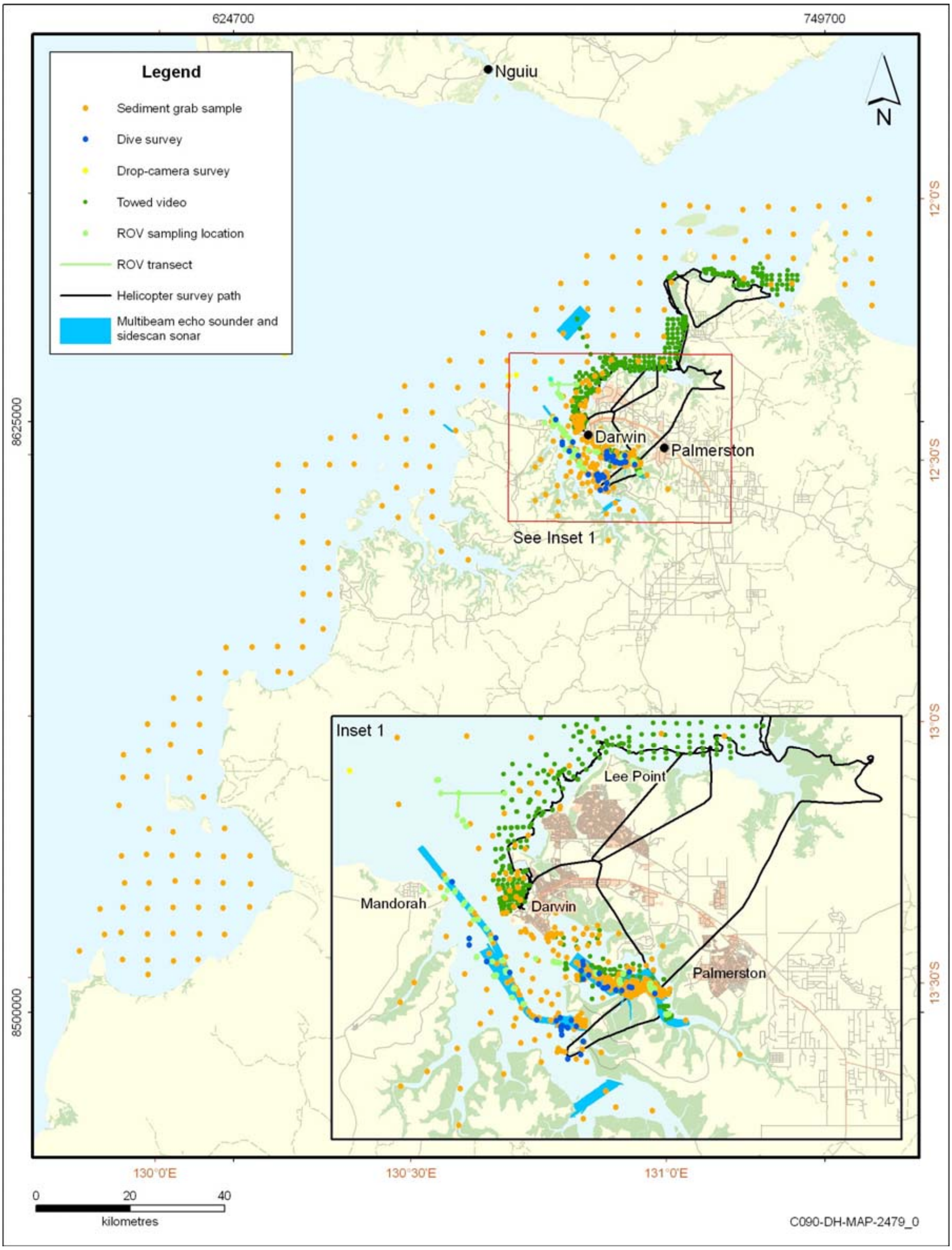
The point data contains data from the fields listed in Table 2. When the data was not available the field cells were left blank. The total rows of point data contributed by each survey are listed in Table 2. The data points collected from each survey is displayed in Figure 11.

- **Table 2 Data fields contained in the habitat point data**

| Field name | Description |
|---|---|
| Contractor | Contractor |
| Project | Project |
| Site_ID | Transect or site name |
| Lat | Latitude |
| Long | Longitude |
| Substrate | Reef and/or sediment |
| Reef Cover | % composition of reef and sediment substrate |
| Reef Structure | Reef particle size |
| Reef Profile | Reef profile |
| Sediment Structure | Sediment particle size |
| Sediment Profile | Sediment profile |
| Community | Community type |
| Total biota cover | % cover of total biota |
| CA_Spp | Canopy algae biota present |
| SA_Spp | Small algae biota present |
| MA_Cover | Macroalgae % cover |
| MA_total | Macroalgae % cover of total biota cover |
| SG_Spp | Seagrass biota present |
| SG_Cover | Seagrass % cover |
| SG_Total | Seagrass % cover of total biota cover |
| HC_Spp | Hard coral biota present |
| HC_Cover | Hard coral % cover |
| HC_total | Hard coral % cover of total biota cover |
| SC_Spp | Soft coral biota present |
| SC_cover | Soft coral % cover |
| SC_total | Soft coral % cover of total biota cover |
| FF_Spp | Filter-feeders biota present |
| FF_cover | Filter-feeders % cover |
| FF_total | Filter-feeders % cover of total biota cover |
| Other_biota | Other biota attributes |
| Video_Com | Video comments |
| Depth | Depth (meters) (raw data) |
| Date | Date of data capture |
| Time | Time of data capture (UTM) |
| Video_Qual | Video quality |
| Interpreter | Video analyst |

- **Table 3 The number of rows of data from the different studies that was combined into the known-point data set**

| Data Source | Survey | Methods | Rows of data | |
|---|---|---|---|---|
| | | | **Sediment** | **Community** |
| NRETAS | Casuarina Beach survey | Qualitative intertidal seagrass survey | | 1408 |
| NRETAS | Fanny Bay Survey | Qualitative intertidal seagrass survey | | 725 |
| URS | Intertidal Aerial Survey | Qualitative analysis of video and still images captured at spring low tide | | 34 |
| URS | Coral Sites | Qualitative description of substrate and community | | 3 |
| URS | Dive Locations Completing ROV | Qualitative description of substrate and community | 21 | 24 |
| URS | First Diving Survey Locations | Qualitative description of substrate and community | 15 | 15 |
| URS | ROV Sampling Record | Qualitative description of substrate and community | 74 | 74 |
| URS | Walker Shoal Dive Survey Nov2010 | Qualitative description of substrate and community | 6 | 5 |
| Geo Oceans | Towed Video Survey | Qualitative analysis of towed video footage | 36000 | 36106 |
| Smit, 2000 | Beagle Gulf Sediment Survey | Quantitative sediment survey using PSD analysis | 158 | |
| Dames and More, 1982 | Channel Island survey | Quantitative sediment survey using PSD analysis | 6 | |
| Parry and Munksgaard, 1997 | Grainsize of Sediment in Darwin Harbour survey (1993) | Quantitative sediment survey using PSD analysis | 114 | |
| URS | Wickham Point, Frances Bay and Stokes Hill Wharf | Quantitative sediment survey using PSD analysis | 29 | |
| **Total rows of data** | | | **36423** | **38394** |




- **Figure 11 The sources of the point data combined into the total known dataset (~38,000 points)**

### 3.2.1. Sediment particle size point data classification

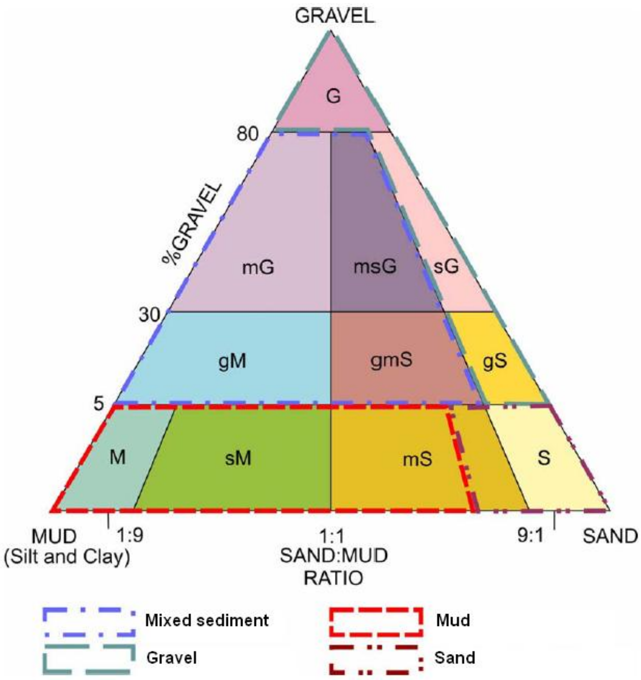
To combine the sediment data from the different surveys a consistent substrate classification scheme was adapted with particle size definitions based on the Wentworth scale (Wentworth, 1922), a geological scale used to define sediment particle size classes. The substrate classification scheme is a hierarchical classification scheme that clumps fine scale sediment class data into broader classes (Figure 8). This allows data collected at different resolutions to be combined to produce to maps of different scales. The sediment particle size distribution map produced for this report used data collected at the level 2 sediment classification classes. The level 2 sediment classification classes, point values and interpolation cell values are listed in Table 4 and Appendix 2.

To combine the sediment point datasets a hierarchical classification scheme was adapted that clumped fine-scale quantitative particle size data into four broad classes (i.e. mud, sand, gravel and rock). Quantitative data was only used if full-grain size analyses were conducted. The full-grain size analyses sediment data were classified to sediment classification level 3 based on grain size analysis. The level 3 classifications have been merged into a higher sediment classification level 2 (i.e. mud, sand, gravel and rock) that can be distinguished from video or in situ descriptions using the groups listed in the sediment classification triangle (Figure 12) and Figure 8. Mixed and unsorted sands indicate that there were more or less equal parts of fine- medium and coarse sands in the sediment sample and were classed as sand. The level 2 data from all surveys were combined to produce a total data set of 35,423 rows of data throughout the survey area (

Table 3).

- **Table 4 Decision rules for the sediment particle size level 2 classes**

| Sediment class | Particle diameter | Interpolation values | |
|---|---|---|---|
| | | Point values | Cell values |
| Mud | < 0.6mm | 0 | 0 to 0.5 |
| Sand | 0.6mm to 2mm | 1 | 0.5 to 2 |
| Gravel | 2mm to 64mm | 3 | 2 to 4 |
| Rock | >64mm | 5 | >4 |




- **Figure 12 Reclassification classes of the sediment classification triangle (Folk, 1954)**

## 3.3. Benthic communities point data classification

The total community point data consisted of 38,394 rows of data from 9 different surveys (Table 2). The URS diver and ROV surveys and the Geo Oceans towed video survey data was used to classify the subtidal habitats. The NRETAS seagrass survey and URS aerial survey data was used to classify and map the intertidal habitats. Figure 13 shows the total community point data.

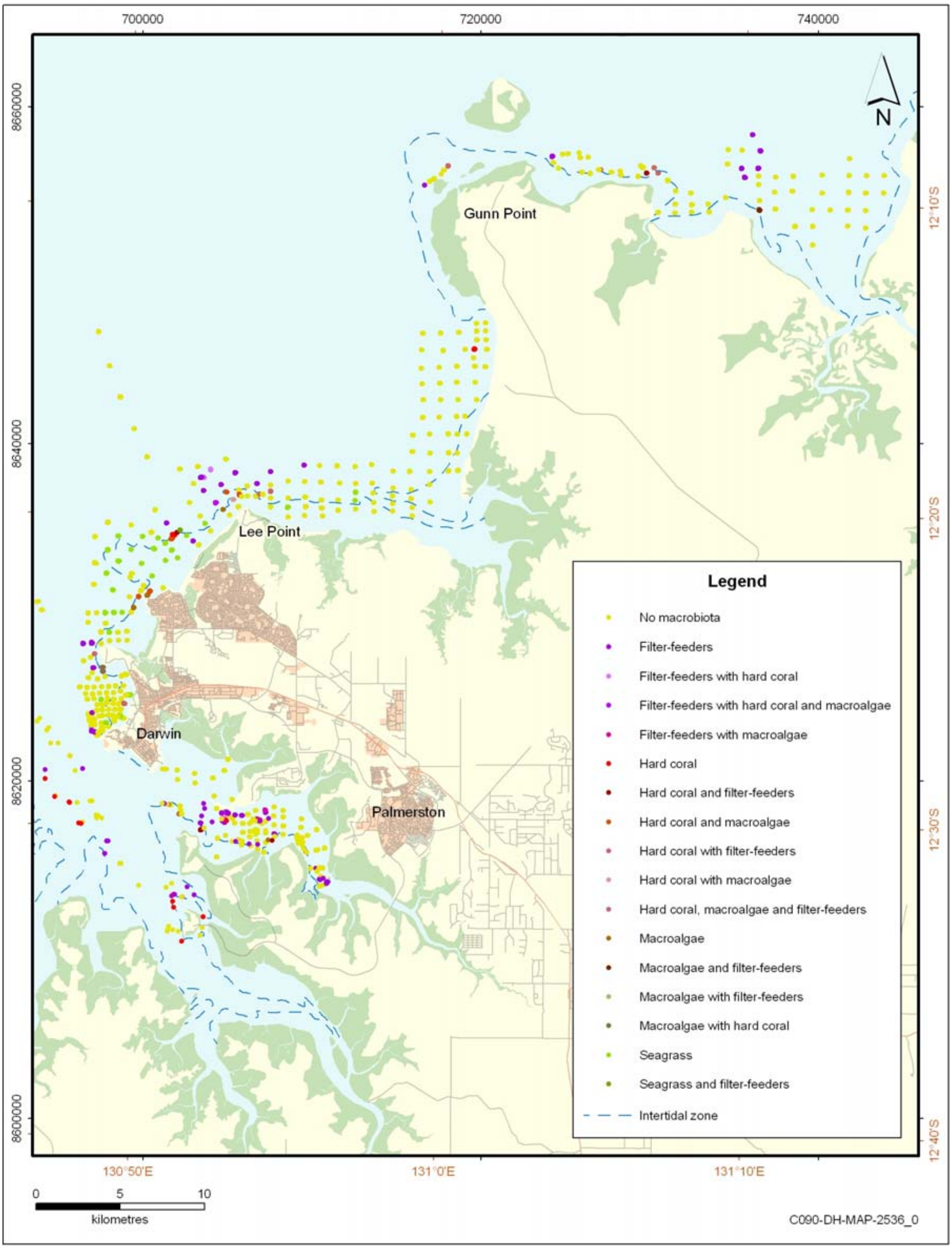
A total of 36, 207 rows of subtidal point data consisted of the Geo Oceans towed video survey data (36,106 rows) and the URS diver and ROV survey data (121 rows). The towed video survey used qualitative community class cover estimates from the towed video footage along transect lines, using a sampling design that sampled all of the benthic habitats in the survey area described in detail in Section 2.1.

A total of 2167 rows of intertidal point data consisted of the NRETAS seagrass survey data at Casuarina Beach (1408 rows) and Fanny Bay (725 rows) and the URS aerial survey (34 rows). The NRETAS seagrass survey collected qualitative seagrass species percent cover estimates on a walking survey at spring low-tide. The URS aerial survey captured geo-referenced still images and video footage from a helicopter at spring low tide. The images were analysed using qualitative community class percent cover estimates consistent with the INPEX habitat classification scheme (Appendix 1).

The community point data was classified into a single community type using the percent cover attributes of the different biota classes. The community types were defined by the dominant and co-dominant community types using similar decision rules in Table 5. Table 5 is a modified version of the “nomenclature and decision rules for benthic community types” provided by NRETAS. The decision rules are based on the percent cover composition of the biota classes of the total biota cover.

- **Table 5 Point data community types classification decision rules and nomenclature.**

| Community types classification | Example | Biota class composition |
|---|---|---|
| Dominated by biota class | Hard coral | Biota class is >90% composition of total biota |
| Dominant biota class ***with*** other biota classes present | Hard coral ***with*** macroalgae | Dominant biota class <90% with other biota 10 to 30% composition of total biota |
| Co-dominant biota classes (***and***) | Hard coral ***and*** macroalgae | Co-dominant biota classes >30% composition of total biota |




- **Figure 13 Community type point data**

## 3.4. Habitat and sediment particle size distribution maps

The classified subtidal sediment and community point data was interpolated using geographic information system (GIS) software to produce broad scale distribution maps throughout the study area. The total point datasets were interpolated using spline interpolation (spline with barriers) in ArcGIS 9.3. Spline interpolation uses a mathematical function to create a continuous surface of cell values between the values at the known point sample locations. The interpolation boundaries were digitised using the Australian coastline GIS vector (Geoscience Australia, 2004) as the inner boundary and the outer points as the seaward boundary.

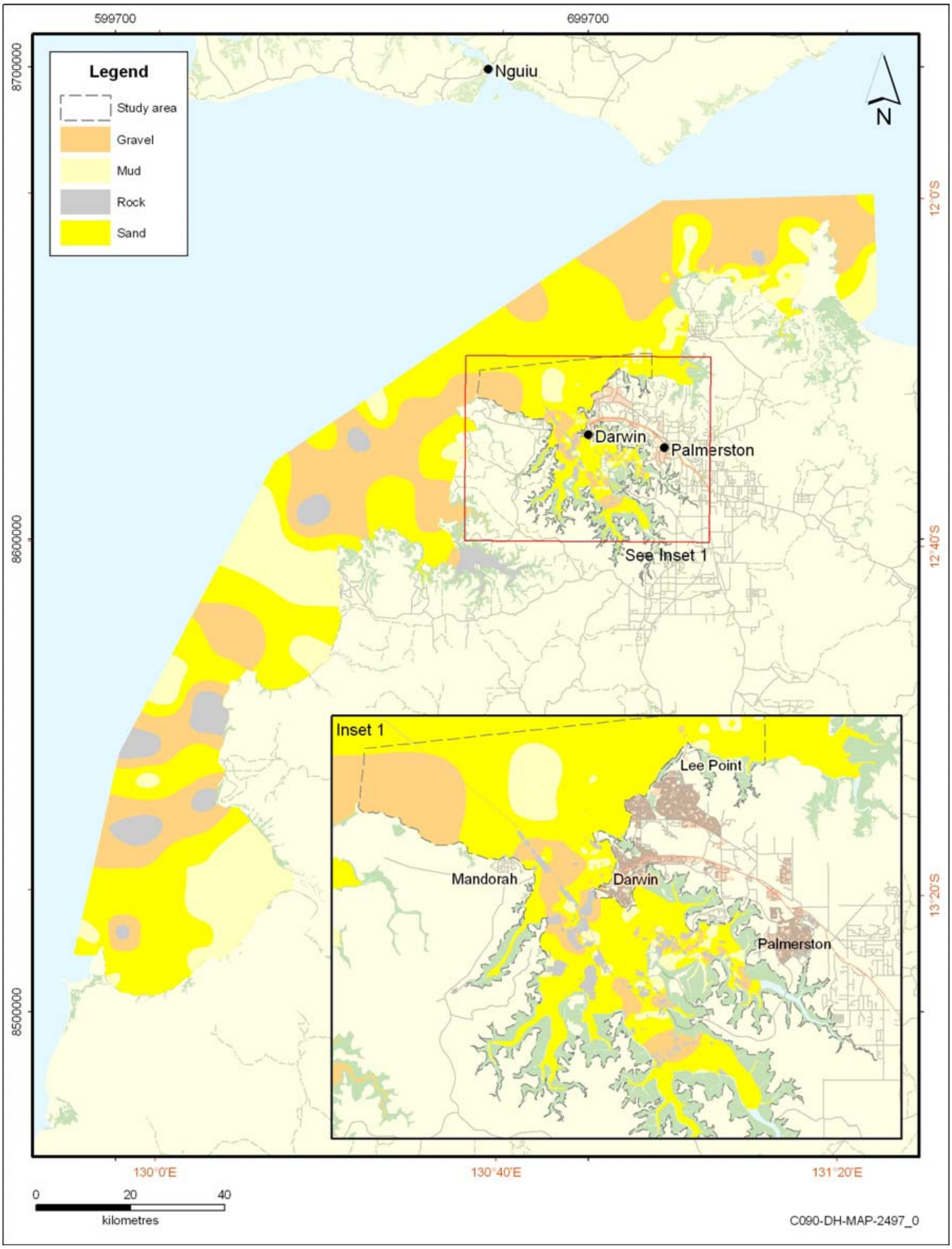
Each point sample location had a value assigned to the habitat attributes. The attribute values that were used for the interpolation were calculated from the dataset using the percent cover and the sediment particle size ranges for the biota and sediment particle size interpolations respectively. The interpolation values for the biota cover classes and sediment particle size classes are listed in Appendix 1 and Appendix 2.

The spline interpolation produces a raster surface of cell values within the interpolation boundary. The raster values were reclassified into integer (whole number) classes to prepare the raster data for conversion into a polygon feature. The reclassification process converts a range of cell values into a single value according to the interpolation values decision rules for cover classes and cover values  (e.g. biota cover cell values between 60% to 80% cover were reclassified with a value of 70). The reclassified raster layers were converted into polygons shapefiles for processing as described in Section 3.5 and Section 3.6.

### 3.5. Sediment particle size map

The interpolated sediment particle size distribution map was classified into the level 2 sediment particle size classes in the INPEX habitat classification scheme (i.e. mud, sand, gravel and rock) (Figure 10). The distribution of the different sediment particle sizes was mapped by assigning the point interpolation values for the sediment particle size class listed in Table 4.  The interpolation is used to produce a continuous surface of the particle sizes across the survey area with values ranging from 0 to 5. The cutoff thresholds to distinguish between predicted sediment size classes was set as the mid value between the class values, with cell values between the values classified as the sediment class. (e.g. sediment point value = 1; cell value range from 0.5 to 1.5 = mud) (Table 4).

The interpolated sediment particle size distribution map was combined with geophysical acoustic survey data (Fugro, 2008) to produce a sediment particle size map. The acoustic survey classified reef and sediment substrate with high spatial accuracy in targeted areas in Darwin Harbour. The areas identified as rock in the acoustic survey were combined with the interpolated sediment particle size map to produce a broad scale sediment particle size map (Figure 14).




- **Figure 14: Sediment particle size map**

## 3.6. Habitat distribution map

### 3.6.1. Interpolated subtidal habitat distribution map

Percent cover maps were produced for all of the biota classes listed in Appendix 1 (i.e. Hard Coral, Macroalgae, Filter-feeders, Soft Coral and Seagrass) using the spline interpolation methods described in Section 3.4. The same methods were used to produce a reef substrate distribution map using the substrate percent cover values listed in Appendix 2. The percent cover raster values were reclassified to display a biota class presence / absence (distribution) map for each of the biota classes and the reef substrate map. The percent cover threshold decision rules for attribute presence were as follows:

- >10% for hard coral, filter-feeders and macroalgae;
- >1% for seagrass; and
- >25% for reef substrate.

The biota and substrate distribution maps were combined into a single habitat map using the Arc GIS Spatial Analysis 'raster calculator' function. The combined habitat raster map was converted into a polygon feature and classified into the habitat classes listed below:

- Hard Coral; Reef
- Macroalgae; Reef
- Filter-feeder; Reef
- Mixed Community; Reef
- < 10% Macrobiota; Reef
- Soft bottom benthos; Sediment
- Seagrass; Sediment
- Mangrove; Sediment

The reef substrates with a mix of biological communities present (i.e. coral, macroalgae and filter-feeder community assemblages >10% cover) in 0 to -5 meters LAT were classed as mixed communities. The proportion of each biological community in the mixed communities class was calculated using the percent composition of the community groups in the high confidence area on all reef substrates, within the depth range of 0 to -5 meters LAT. The calculation defined the ratio of biological communities on mixed reef as:

Mixed reef = <10% macrobiota 47% : hard coral 15% : macroalgae 8% : filter-feeder 29%.

### 3.6.2. Geophysical survey data classification

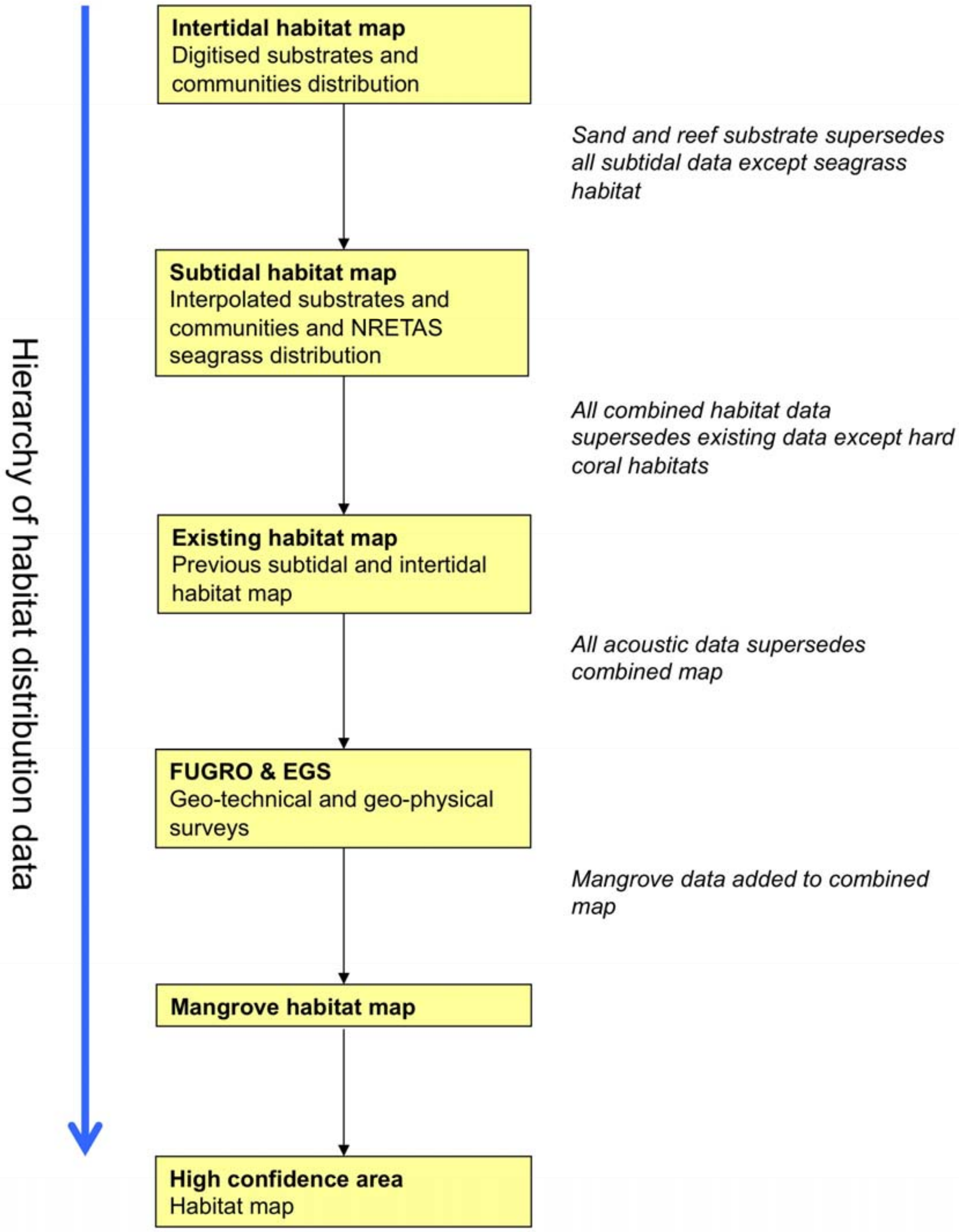
The geophysical surveys used data collected by acoustic echo-sounder equipment to model the seabed features and sediment distribution with high spatial precision, along a proposed gas export pipeline route to Wickham Point and shipping channel and turning basin inside East Arm of Darwin Harbour (Fugro, 2008). The survey accurately modelled the distribution of reef and sediment substrate but not the distribution of biological communities. Therefore, to classify the substrate types it was assumed that all reef substrate mapped in the geophysical survey was capable of supporting biological communities but the mobile soft sediments did not support macro-biota. The biological communities were classified based on depth classes using similar decisions as used for classifying the inferred habitats (described in detail in section 3.6.4). The substrates identified in the geophysical survey were classified using the following habitat classes:

- Reef substrate in water depth between 0-5 LAT = Mixed community; Reef
- Reef substrate in water depth greater than 5m LAT = Filter-feeder; Reef
- Sediment substrate = Soft bottom benthos; Sediment

### 3.6.3. Collating habitat distribution data – high confidence areas

The decision process for combining the different habitat distribution data is displayed in Figure 15. The process involved prioritising data collected using the data that best represent the distributions of the different habitats while using conservative decisions to include all credible data of important habitats (e.g. hard coral and seagrass distribution data).

The interpolated sub-tidal habitat maps were combined with the intertidal habitat distribution map. The intertidal habitat maps accurately display the distribution of reef and sediment substrates in the intertidal zone but the distribution of seagrass was too difficult to discern from the aerial images. Therefore, the intertidal habitat map superseded all subtidal habitat data except the distribution of seagrass (i.e. the intertidal map was overlaid on top of the subtidal map for all habitats except the seagrass habitats). The combined intertidal and interpolated subtidal map superseded all of the existing habitat map except the habitats previously mapped as hard coral habitat and the geophysical survey maps. This produced a combined subtidal and intertidal habitat map. The combined subtidal and intertidal habitat map was combined with the existing mangrove habitat map to produce a habitat map within the surveyed (‘high confidence’) areas. The high confidence areas are the areas that were surveyed with adequate data to produce a high confidence areas habitat map.




- **Figure 15 Decision process to combine the habitat distribution data**

### 3.6.4. Inferred habitat areas

The proportion of benthic habitats in the survey area between Fannie Bay to Lee Point (high confidence area) were used to represent the remaining areas outside of the high confidence area, to produce ‘inferred habitat’ areas. The percent cover of the benthic habitats in the inferred habitat areas was classified using the percent cover of the biological communities and substrate types (benthic habitats) within the high confidence area for different water depth classes (Table 6). The relationship between water depth and the type of benthic habitats present was determined by counting the occurrence of the biological communities present on reef and sediment substrates within defined depth classes, using the known point data in the high confidence area (Table 7). The biological communities changed composition from a mix of photosynthetic and heterotrophic communities to a heterotrophic dominant habitat at a water depth of approximately -5 meters LAT. The photosynthetic macroalgae and coral communities and heterotrophic filter-feeder communities were all present in the intertidal and shallow sub-tidal zones from +2 to -5 meters LAT of water depth. However, only heterotrophic filter-feeder communities were present on reef substrates in water depth deeper than -5 meters (LAT). Seagrass was recorded on mud and sand sediments in the intertidal and shallow subtidal zones from +2 to -5 meters LAT. Macroalgae, coral and filter-feeders were only found to be present attached to reef substrate.

- **Table 6: The 'inferred habitats' percent cover calculations and classification**

| Inferred Habitat | Depth class | Habitat class | % of area | Benthic habitat ratio |
|---|---|---|---|---|
| Seagrass:Sediment | Intertidal | Seagrass; Sediment | 22% | Seagrass : Sediment 22%:88% |
| Seagrass:Mixed Reef:Sediment | 0 to -5m LAT | Seagrass; Sediment | 18% | Seagrass : Mixed Reef : Sediment 18%:5%:77% |
| | | Mixed community; Reef | 5% | |
| Mixed Reef : Sediment | 0 to -5m LAT | Mixed community; Reef | 5% | Mixed Reef : Sediment 13%:87% |
| | | No macrobiota (<10% cover); Reef | 4% | |
| | | Hard coral; Reef | 1% | |
| | | Filter-feeders; Reef | 2% | |
| | | Macroalgae; Reef | 1% | |
| Filter-feeders:Sediment | >-5m LAT | Filter-feeders; Reef | 29% | Filter-feeders : Sediment 29%:71% |

- **Table 7 Biological communities present in each depth class (using the point data).**

| Depth range | Intertidal | | 0 to -2m | | -2 to -5 | | -5 to -10m | | -10 to -15m | | -15 to -20m | | -20 to -30 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Habitat Classes** | **Count** | **%*** | **Count** | **%*** | **Count** | **%*** | **Count** | **%*** | **Count** | **%*** | **Count** | **%*** | **Count** | **%*** |
| *Biota classes* | | | | | | | | | | | | | | |
| **Seagrass** | 2735 | 14% | 1335 | 17% | 257 | 6% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% |
| **Macroalgae** | 2834 | 57% | 509 | 38% | 128 | 12% | 0 | 0% | 0 | 0% | 0 | 0% | 0 | 0% |
| **Hard coral** | 2597 | 52% | 580 | 43% | 74 | 7% | 0 | 0% | 2 | 1% | 0 | 0% | 0 | 0% |
| **Filter-feeders** | 2651 | 53% | 1193 | 88% | 1086 | 100% | 288 | 100% | 196 | 87% | 4 | 100% | 8 | 100% |
| *Substrate classes* | | | | | | | | | | | | | | |
| **Reef** | 4972 | 21% | 1349 | 15% | 1086 | 21% | 288 | 11% | 226 | 37% | 4 | 24% | 8 | 42% |
| **Sand** | 19051 | 79% | 7629 | 85% | 4113 | 79% | 2318 | 89% | 379 | 63% | 13 | 76% | 11 | 58% |

* % column is the percent of the biological class present on available substrate

Benthic sampling in the high confidence areas showed that the seagrass communities were only present on the sand substrates in the shallow bays from Fanny Bay to the south west side of Shoal Bay and were not found in Darwin Harbor or Adam Bay. The oceanographic conditions in those areas where seagrass was present in the high confidence areas is similar to the coastal waters between Mandorah and Charles Point. Therefore, the inferred habitat areas likely to contain seagrass communities were mapped as the sand substrates in the intertidal and subtidal zones from +2m to -5 meters LAT between Mandorah and Charles Point.

The inferred habitat area in Shoal Bay was classified as 'soft bottom benthos; sediment' with no macro-biota or reef communities present. This inferred habitat was classified using the known point data in the adjacent high confidence area and the geophysical survey data in the dredge spoil. The inferred habitat boundary (area) was digitised using the areas of Shoal Bay where the Seafarer bathymetry charts showed consistent bathymetry contours indicating a flat, featureless seafloor consisting of sediment with no reef present.

The spatial coverage of the habitats in the inferred habitat areas was defined by extrapolating the inferred habitats throughout the areas outside of the high confidence areas, using the depth data from the Australian Hydrographic Survey admiralty charts.

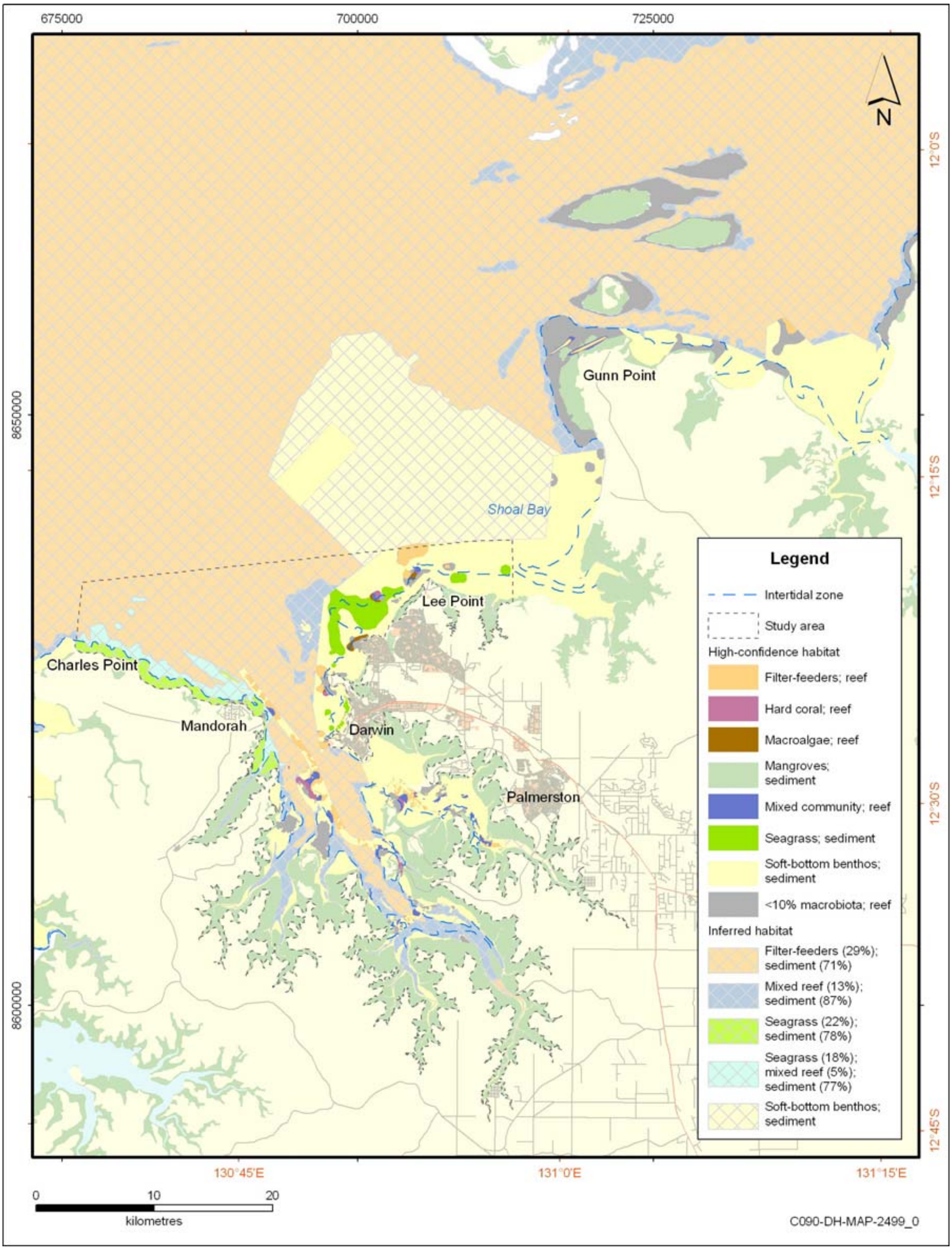
### 3.6.5. Benthic habitat map

The inferred habitat and high confidence habitat maps were combined to produce a benthic habitat map showing the distribution of the benthic communities and substrates throughout the mapped areas (Figure 16). The benthic habitat map predicts the spatial area and distribution of the benthic communities and substrates throughout the management area to allow calculations for impact assessment. The area of each habitat class in the study area used for impact assessment is displayed Table 8.

- **Table 8 Benthic habitat area calculations in the study area (Figure 16)**

| | Habitat type | Area (Ha) | Hard coral | Filter-feeder | Macro-algae | Sea-grass | Sand | Mud | Gravel | Sedi-ment | Mang-roves |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **High confidence habitats** | **Filter-feeders; reef** | 1258 | | 1258 | | | | | | | |
| | **Hard coral; reef** | 219 | 219 | | | | | | | | |
| | **Macroalgae; reef** | 134 | | | 134 | | | | | | |
| | **Mangrove; sediment** | 21456 | | | | | | | | | 21456 |
| | **Mixed community; reef** | 433 | 65 | 126 | 35 | | | | | | |
| | **No macrobiota (<10%); reef** | 1749 | | | | | | | | | |
| | **Soft-bottom benthos; Sediment** | 16377 | | | | | | | | 16377 | |
| | **Seagrass; sediment** | 1734 | | | | 1734 | | | | | |
| **Inferred habitats** | **Filter-feeders (29%); sediment (71%)** | 21516 | | 6240 | | | | | | 15276 | |
| | **Mixed reef* (13%); sediment (87%)** | 6640 | 129 | 250 | 69 | | | | | 5777 | |
| **Sediment particle size data** | **Gravel** | **11193** | | | | | | | **11193** | | |
| | **Mud** | 5728 | | | | | | 5728 | | | |
| | **Rock** | 2900 | | | | | | | | | |
| | **Sand** | 35409 | | | | | 35409 | | | | |
| **Total inferred area (ha)** | | | 146 | 6528 | 78 | 786 | | | | 24681 | |
| **Total high-confidence area (ha)** | | | 284 | 1384 | 169 | 1734 | 35409 | 5728 | 11193 | 16377 | 21456 |
| **Total study area (ha)** | | 76042 | 430 | 7912 | 247 | 2520 | 35409 | 5728 | 11193 | 41058 | 21456 |

* Mixed Community; Reef = NM 47%:HC 15%: FF 29%: MA 8%




- **Figure 16 Benthic habitat map**

# 4. Description of benthic habitats

The benthic habitats, seabed features and sediment distribution within the surveyed areas are highly influenced by the strong tidal currents that flow through Darwin Harbour, particularly in the inner harbor areas. The prevalence of strong tidal currents flowing over the uneven bedrock surface appears to have had a major contributing influence on the form and composition of the reef substrates and the sediments deposited over that surface. The seabed topography within the inner areas of Darwin Harbor varies from smooth and gently undulating with slope gradients of <0.5° to locally very uneven over outcropping ridge features, on the sides of channels and over sandwaves and sandbanks, with measured slope gradients in excess of 1:2 (Fugro, 2008).

The majority of the benthic habitats in the East Arm extension of Darwin Harbor consists of soft bottom benthos communities living in unconsolidated sediments. The surficial sediments and thicker sediment deposits comprise of fluvial muds (i.e. clays, and silts) sands and gravels, with the finer fractions becoming more dominant in the intertidal zones and in areas of more sheltered waters. The actual composition of these sediments is expected to vary considerably throughout the surveyed areas both laterally and vertically due to the active depositional environment. The presence of sandbanks, sandwaves and megaripples indicate a significant degree of sediment mobility. No seagrass or other macrobiota was recorded growing in the sediments in East Arm.

The reef substrates in the inner harbor (including East Arm) consists of outcropping bedrock (reef) surface that varies from relatively smooth to uneven due to the presence of slopes and ridge features. Many of the ridges are inferred to indicate the presence of steeply dipping beds of harder sandstone/quartzite that are more resistant to weathering and erosion (Fugro, 2008). The exposed reef substrates are dominated by filter feeding communities composed of gorgonian fans and sea whips (family Gorgonia), soft corals (family Alcyonica) and sponges which thrive on the food provided by the strong currents and highly turbid waters. Small communities of hard corals are found in the shallow subtidal and intertidal reefs adjacent to the East Arm wharf mixed with the filter-feeder communities. The hard corals communities consist of the growth forms (morphology) of massive (i.e. family Favidae), foliose (i.e. genera Turbinaria) and encrusting (e.g. family Favidae) corals.

The inshore waters between Fannie Bay and Shoal Bay consists of rocky points that extend into intertidal and subtidal reef platforms, interspersed by bays of soft sediments.

The soft sediments in the sheltered bays of Fannie Bay and Casuarina Beach support seagrass communities that are dominated by *Halodule* spp. (e.g. *Halodule uninervis*) with *Halophila* spp (i.e. *H. decipiens*, *H. spinulosa* and *H, ovalis*) and *Syringodium* sp. The majority of the seagrass was found in the lower littoral intertidal zone between 0 to +1 LAT but sparse communities extended out to -3m LAT into the sub-tidal zone.

The reef communities between Fannie Bay and Shoal Bay had a similar community structure that changed with increasing water depth from a mixed community of macroalgae (e.g. *Caulerpa* spp., *Halimeda* spp, and *Sargassum* spp.), hard coral (e.g. *Favidae* spp. and *Turbinaria* sp.) and filter-feeders in the lower-littoral intertidal zone and shallow sub-tidal to a filter-feeder dominant habitat at approximately -3m LAT. Old Man Rock supports a dense community of branching *Acropora* sp. on the northern aspect but on the southern aspect is dominated by the mixed communities of macroalgae, coral and filter-feeders that are typical of the shallow reefs in the region. The mid-littoral to the upper-littoral intertidal reef substrates from Fannie Bay to Lee Point did not support any significant macro-biota communities (macrobiota < 10% cover).

# 5. Limitations of the mapping methods

Using the methods discussed in this report to collate all of the data collected from different survey methodologies has improved the detail in the existing habitat maps. The maps can continually be updated with additional data using a habitat classification scheme that is consistent with the decision rules and definitions used in this report. However, mapping marine habitats is a difficult task compared with mapping terrestrial habitats, particularly in areas of high turbidity such as in Darwin Harbour. There are limitations to the accuracy of the classification and spatial precision (scale) of the maps described in this report.

The habitat and sediment maps were produced using different data collection and processing methodologies. The accuracy and scale of the maps depends on the accuracy and intensity of the sampling (e.g. number of data points). These maps used various data sources collected using methodologies with different levels of accuracy (i.e. qualitative surveys are less accurate than quantitative surveys; recently collected data is more accurate than older data). The intensity of sampling also varied throughout the survey area resulting in areas of different scales in the map (e.g. Darwin Harbour is surveyed more intensely than the outer extent of the Beagle Gulf). Therefore, it is not possible to quantify the accuracy or scale of the maps. The known data sources and survey methods used to collect and classify the data should be considered when using these maps.

## 5.1. Sediment particle size map

The primary aim of the sediment particle size map was to predict the distribution of sediments within the study area using all the available data - the map is intended as a broad scale representation of the patterns in sediment particle sizes distribution. The spatial extent of these surfaces is difficult to determine due to the lack of accurate data, the gradual transition between muddy, sandy and coarser sediments and sediment movement associated with large tidal influences.

Outside the greater Darwin region the only source of data was the quantitative Beagle Gulf sediment particle size data (Smit et al, 2000) that was highly accurate using particle size analysis methods but due to the low number of sampling locations (i.e. one sample every 2km) the data is at a very broad scale. In particular, Bynoe Harbour is classified as rock because the one data point sampled in that region was rock and this data was interpolated throughout the Harbour. However, sediment is also present in this area. Darwin Harbour was surveyed more intensely and this mapped the sediment particle size at a finer scale. However, the accuracy of the data may be reduced because the majority of the data was collected using qualitative estimates of sediment particle size (i.e. diver and towed video methods) and the sediment size distribution analysis data (quantitative analysis) collected during the Parry and Munksgaard (1997) survey was collected 15 years ago.

## 5.2. Benthic habitat map

The spatial distribution and habitat boundaries of the subtidal benthic habitats were defined using interpolation of available point data. The scale of the maps using this method is dependant on the number of data points collected and varies throughout the study area. To produce more accurate habitat boundaries of subtidal habitats, aerial and satellite images or detailed bathymetry collected by geotechnical methods (e.g. laser airborne depth sounder (LADS); acoustic) can be modelled using the known point data to classify the habitats. However, Darwin Harbour has extremely turbid water, which may limit the effectiveness of images and LADS data collection.

### 5.2.1. Inferred habitats

The inferred habitat areas were created to predict the polygons of benthic habitat areas where there was not enough data to map these marine habitats with high confidence. The inferred habitat area calculations are modelled on the high confidence data assuming that the ratio of biological communities in the high confidence areas are the same as the ratio throughout the inferred habitat area. The inferred habitat areas can be updated with known habitat data when the data becomes available.

### 5.2.2. Mixed community class

The mixed community class was used to classify the substrates that were mapped as hard (reef) substrate in the geotechnical (acoustic) survey but did not have known point data to classify the habitats into biological community classes and for the mixed community class in the inferred habitat area. The mixed community class was calculated from the high confidence area between Fanny Bay and Lee Point and assumes that the ratio of biological communities on reef substrate in water depth between 0 to -5m LAT in this area is the same as the mapped areas with these substrate and depth attributes, outside the high confidence area.

# 6. References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6. Mount, R., Bircher, P. and Newton, J. 2007. *National Intertidal/Subtidal Benthic Habitat Classification Scheme*. School of Geography and Environmental Studies, University of Tasmania

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# Appendix 1 Habitat Classification Definitions

| Biota Classes | Morphological groups | Definitions and examples |
|---|---|---|
| **Encrusting / turfing algae** Only recorded for presence/absence | | |
| | Microphytobenthos (MPB) | Thin film layer |
| | Crustose coralline algae (CCA) | Encrusting algae |
| | Turfing algae | Hair-like algae <20mm |
| | Filamentous algae | Hair-like algae >20mm |
| **Seagrass** Assemblages >1% over 10m$^2$ | | Separated into genus or species e.g. Halophila, Halodule, Posidonia, Zostera, Amphibolis |
| **Macroalgae** Assemblages >10% over 10m$^2$ | **Red, brown, green** | |
| | **Small Algae** | **Macroalgae 20mm to 20cm** |
| | Membrane, thin sheets | *Padina* spp., *Lobophora* spp. |
| | Foliaceous, bushy | *Caulerpa* spp. |
| | Lobed, flattened and rounded | *Halimeda* spp. |
| | Fleshy or ball-like | *Codium* spp. |
| | **Canopy Algae** | **Macroalgae >20cm** |
| | Flat | *Ecklonia radiata* |
| | Branching | *Cystophora* spp., *Sargassum* spp., other fucoids |
| **Hard Coral** Assemblages >10% over 10m$^2$ | Branching | At least 20 branching (e.g. *Seriatopora hystrix*) |
| | Digitate | Less than 20 branching (e.g. *Acropora digitifera*) |
| | Tabular | Horizontal flattened plates (e.g. *Acropora hyacinthus*) |
| | Encrusting | Major portion attached to substrate as a laminar plate (e.g. *Porites vaughani*) |
| | Foliose | Coral attached at one or more points, leaf-like appearance e.g. *Turbinaria* spp.) |
| | Massive | Solid boulder or mound (e.g. *Favites* spp.) |
| | Submassive | Tends to small columns, knobs or wedges |
| **Soft Coral (BPP)** Assemblages >10% over 10m$^2$ | Sarco/lobo phyton sp. Sinularia sp | Photosynthetic soft corals (e.g. Alcyoniidae spp. (BPP)) |
| **Filter-feeders (non-BPP)** Assemblages >10% over 10m$^2$ | | **Ahermatypic animals (not defined as BPP)** |
| | Soft Coral (non-BPP) | Non-photosynthetic soft corals (e.g. Gorgonian fans, Alcyoniidae (non-BPP) Dendronepthia spp.) |
| | Sponges | Can note morphological groups |
| | Ascidians | Stalked, encrusting, solitary |
| | Hydroids | |
| | Sea whips | |
| | Gorgonian fans | |
| | Sea pens | |
| | Bryozoan | Foliose, stalked |
| | Anemones | Tube, solitary |
| | Polychaetes | |
| **Biota Cover Classes** | **Interpolation values** | **Decision rules** |
| > 80% | 90 | no substrate visible. |
| 60-80% | 70 | some substrate is visible. |
| 40-60% | 50 | substrate is clearly visible but biota dominates the image frame. |
| 20-40% | 30 | substrate dominates most of the image frame. |
| 10-20% | 15 | substrate dominates most of the image frame. |
| 5-10% | 7.5 | substrate dominates most of the image frame. |
| 1-5% | 3 | trace densities |
| 0-1% | 0 | No significant macro-biota |

# Appendix 2 Substrate class definitions

| **Substrate type** | **Particle sizes are defined using the geological 'Wentworth Scale'** | |
|---|---|---|
| Consolidated (reef) | Substrate predominantly made up of particles of cobble size (>64mm diameter) or larger. | |
| Unconsolidated (sediment) | Substrate predominantly made up of particles of pebble size (<64mm diameter) or smaller. | |
| **Substrate composition** | | **Substrate cover class interpolation values** |
| All sediment | Sediment 100% | 0 |
| Mixed sediment and reef | Reef 1-24% (i.e. sand 76-99%) | 12.5 |
| | Reef 25-49% | 37.5 |
| | Reef 50% | 50 |
| | Reef 51-74%, | 62.5 |
| | Reef 75-99% | 87.5 |
| All reef | Reef 100% | 100 |
| **Reef** | | |
| **Reef Particle Size** | | **Substrate particle size class interpolation values** |
| Cobble | Particles 64-256 mm | 5 |
| Boulder | Particles >256 mm | 5 |
| Rock (unbroken) | Unbroken rock substrate | 5 |
| **Reef Profile** | | |
| High | >4m rise over 2m | |
| Medium | 1-4m rise over 2m | |
| Low | <1m rise over 2m | |
| **Sediment** | | |
| **Sediment Particle Size** | | **Substrate particle size class interpolation values** |
| Pebble | Particles 4-64mm | 3 |
| Gravel | Particles 2-4mm | 3 |
| Sand | Particles 63um-2mm | 1 |
| Mud | Particles <63um | 0 |
| **Sediment Profile** | | |
| Flat | No profile (undulations <1cm) | |
| Small ripples | Undulations 1-10cm high | |
| Medium ripples | Undulations 10-50cm high | |
| Large ripples | Undulations 50-100cm high | |
| Waves | Undulations 1-5m high | |
| Dunes | Undulations >5m high | |
| **Bioturbation** | | |
| None | No evidence of bioturbation | |
| Low | 1-2 disturbances (e.g. burrows or mounds) per metre | |
| Medium | 3-10 disturbances per metre | |
| High | >10 disturbances per metre | |