Appendix B
Benthic Habitat Survey

Department of Defence – Garden Island Benthic Marine Habitat Study

Report

Prepared for Aurecon Australasia Pty Ltd and Department of Defence

Rev 0 | June 2015

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Prepared for Aurecon Pty Ltd and Department of Defence

Prepared by Geo Oceans Pty Ltd

June 2015

Department of Defence – Garden Island
Benthic Marine Habitat Study

Report

Document code: DODGARMAP.401

Revision history

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A	A. Lambo	Aurecon	1 x e-copy	07/05/15	J. Phillips	Technical	05/05/15
B	A. Lambo	Aurecon	1 x e-copy	11/06/15	I. LeProvost (Aurecon)	Technical	11/06/15
0	A. Lambo	Aurecon	1 x e-copy	12/06/15	P. Everson (Aurecon)	Client	12/6/15

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1. Project Background

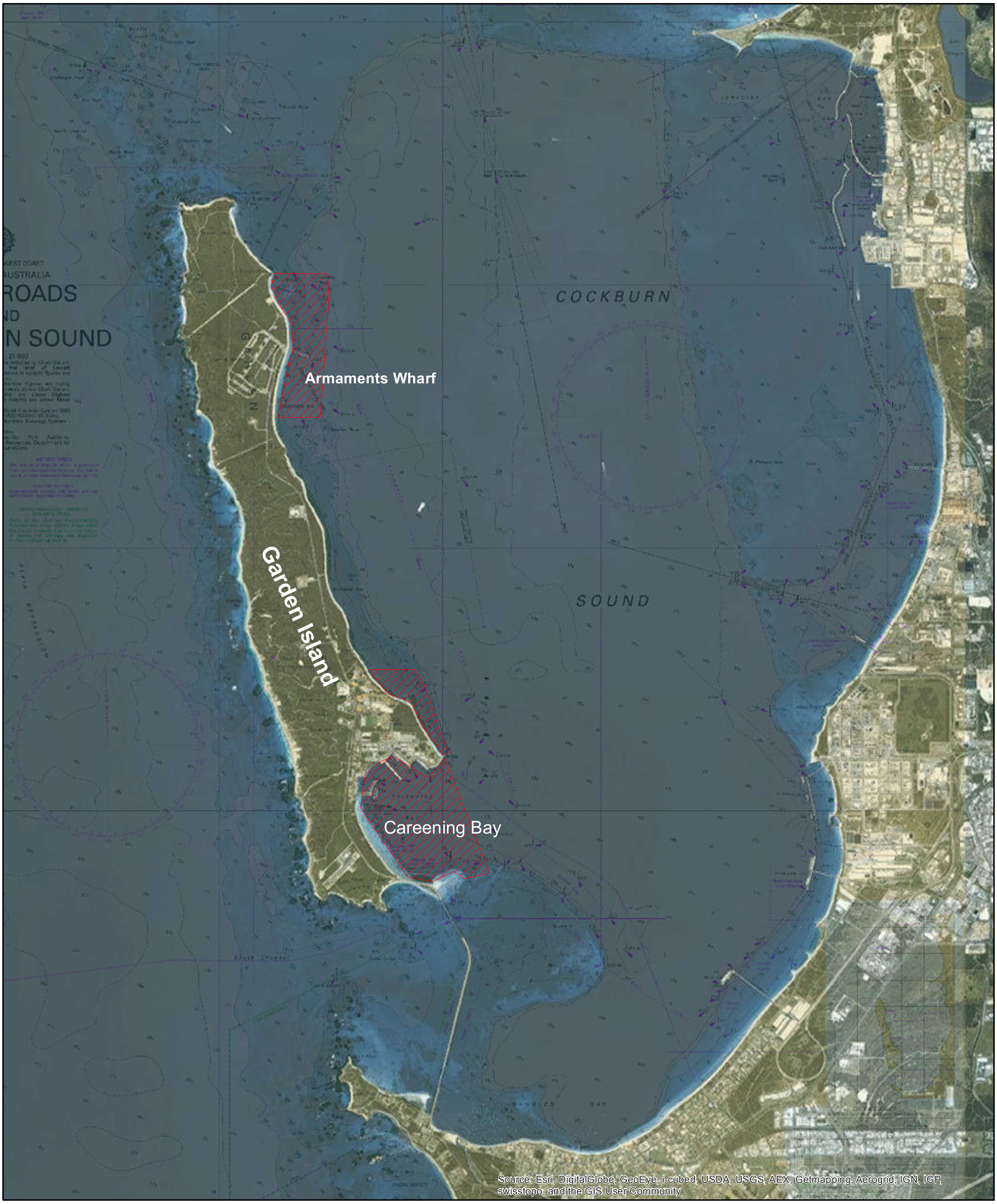
As part of a Department of Defence maintenance dredging programme for H.M.A.S Stirling at Garden Island, Aurecon Australasia Pty Ltd (Aurecon) commissioned Geo Oceans to undertake a pre-dredging benthic habitat baseline mapping study at two proposed dredging locations (Careening Bay and Armament Wharf) within the nearshore area of Garden Island in Western Australia (Figure 1). The study was undertaken in two phases. The initial component of the study was undertaken via a remote sensing classification of the benthic habitats visible from multi-band satellite imagery, with a follow up benthic habitat towed camera survey to ground-truth the predicted habitat boundaries from the remote sensing study. This report consolidates the results of both phases.

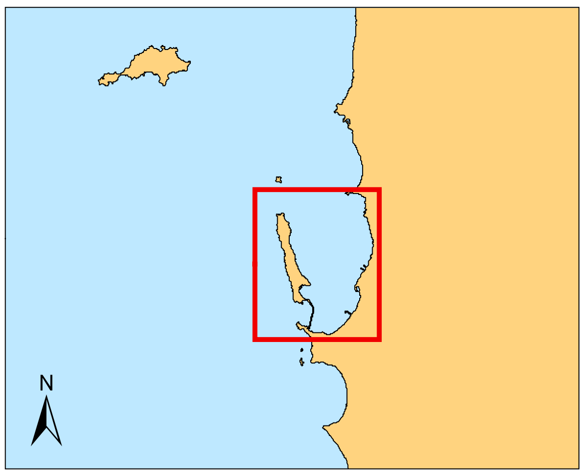
2. Previous Knowledge

Studies undertaken as part of recent proposed development projects (Port Rockingham Marina, RPS 2009 and Mangles Bay Marina, Strategen 2011) as well as the periodic Cockburn Sound Management Council's monitoring activities (DAL Science and Engineering et al. 2004) demonstrates that benthic primary producer habitat (BPPH) within the broader Cockburn Sound area is dominated by seagrass meadows (primarily *Posidonia* spp.), with only a very small area of macroalgae adjacent to the Kwinana refinery (Figure 2, Figure 4, Figure 5 and Figure 6). Off the eastern side of Garden Island, seagrass beds are the dominant BPPH community, with no other significant BPPH communities mapped.

These seagrass communities are dominated by *Posidonia sinuosa* (Figure 6), with occasional patches of *Posidonia australis*, particularly within the 'southern flats' on the eastern side of the Garden Island Causeway (Figure 6). Previous studies have mapped a small distribution of *Amphibolis antartica* seagrass within the Posidonia meadows (RPS 2009), particularly within the beds immediately adjacent to Armament Wharf.

Prior to the industrialisation of Cockburn Sound (pre-1960), approximately 4000 ha of seagrass meadows were present (Figure 3, DEP 1996). These meadows covered much of the nearshore waters, in water depths of 10 m or less. As result of the rapid industrialisation of the area during the 1960s, over 77% of these seagrass beds disappeared, largely due to decreased water quality conditions (nutrient enrichment) and dredging activities associated with port access (EPA 2009). By the late 1970s only approximately 900 ha of seagrass meadows remained within Cockburn Sound (EPA 2009). Since the early 1980s the total seagrass area has remained relatively stable, as improved regulatory oversight has resulted in improved water quality conditions within Cockburn Sound.





Legend

Survey Areas

Imagery Source: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Disclaimer: While all attempts have been made to ensure the accuracy of the information presented, GeoOceans does not guarantee the correctness or suitability of the information for any particular purpose.

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Department of Defence
H.M.A.S Stirling Maintenance Dredging
BPPH Study Areas

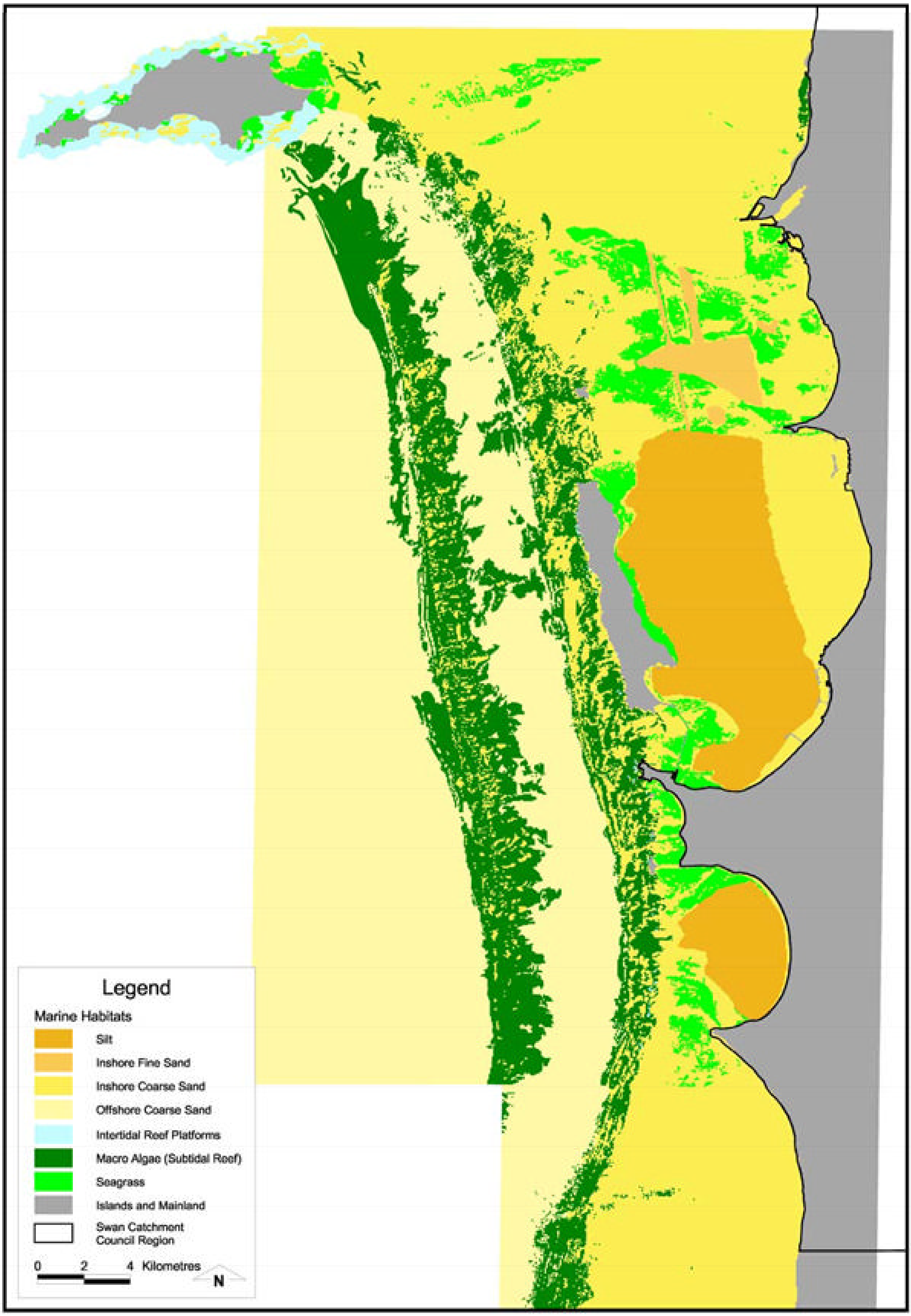
0 1 2 3 km

WGS 1984 Web Mercator Auxiliary Sphere
Projection: Mercator Auxiliary Sphere
Datum: WGS 1984

N

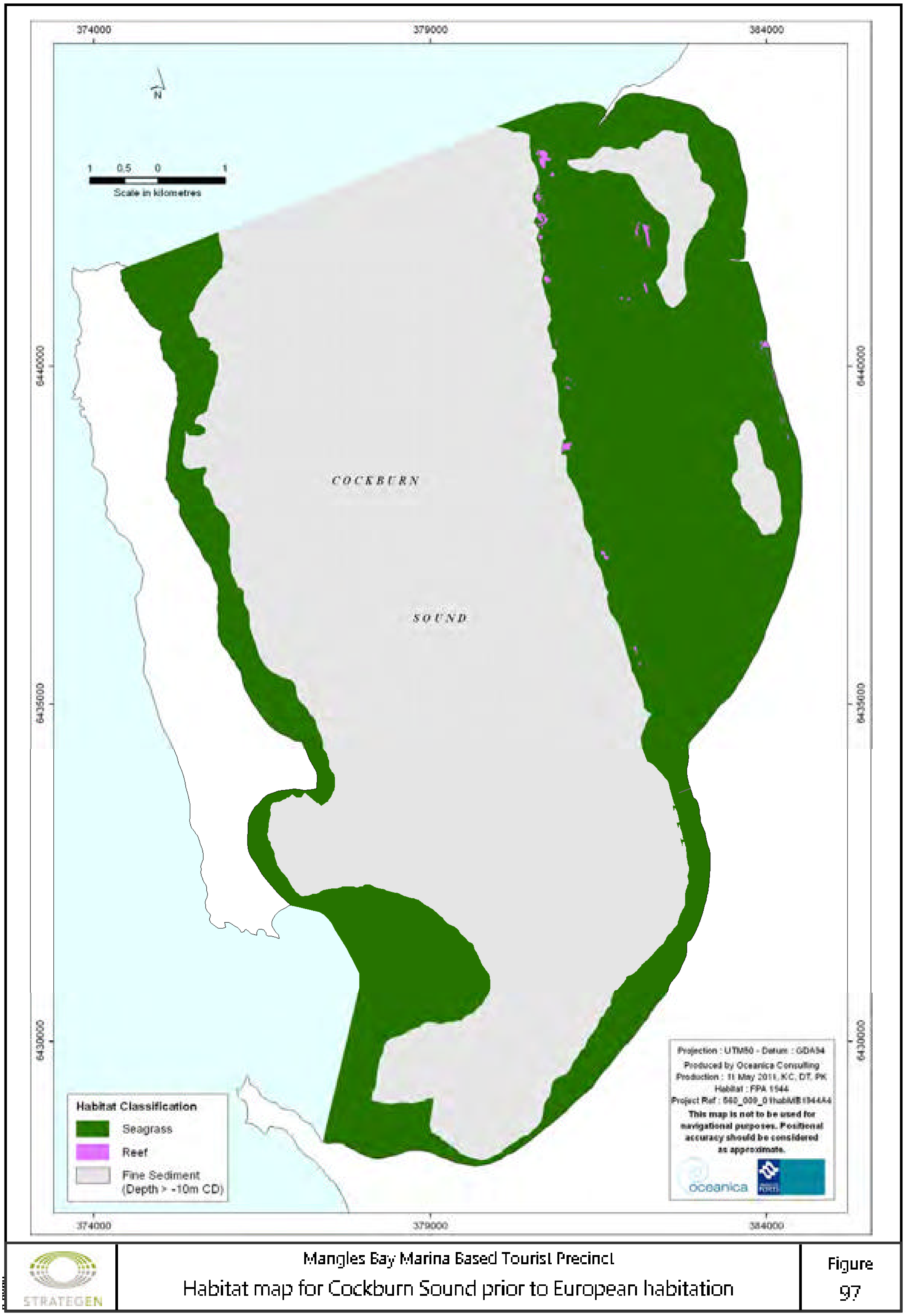
DOTAUGMAP
11/06/2015_AL
60,000 @ A3

Figure 1



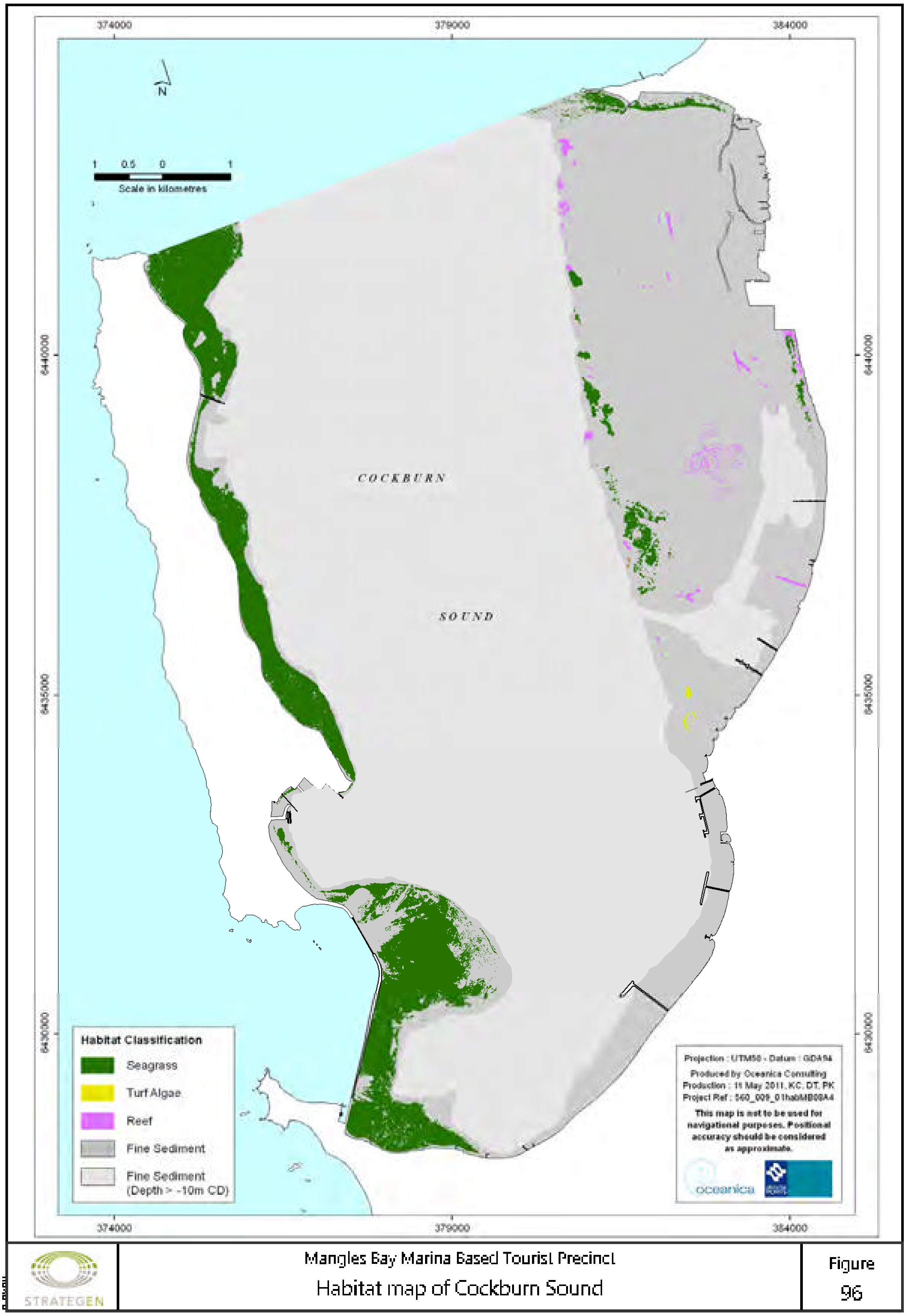
Source: DEP (1996)

Figure 2. Benthic habitats of the Southern Metrepolitan Coastal Waters



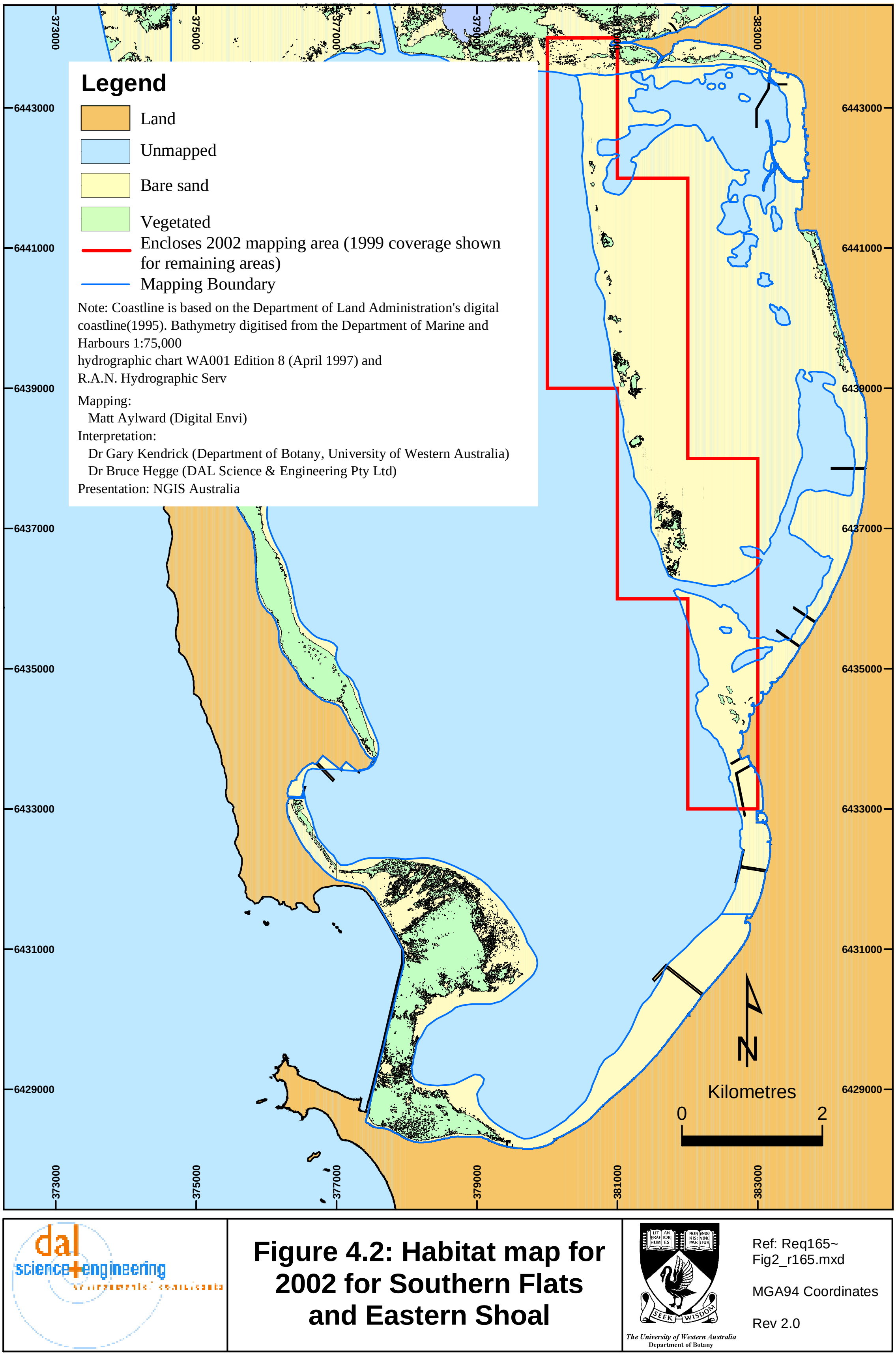
Source: Strategen (2012)

Figure 3. Benthic habitat map for Cockburn Sound prior to European habitation



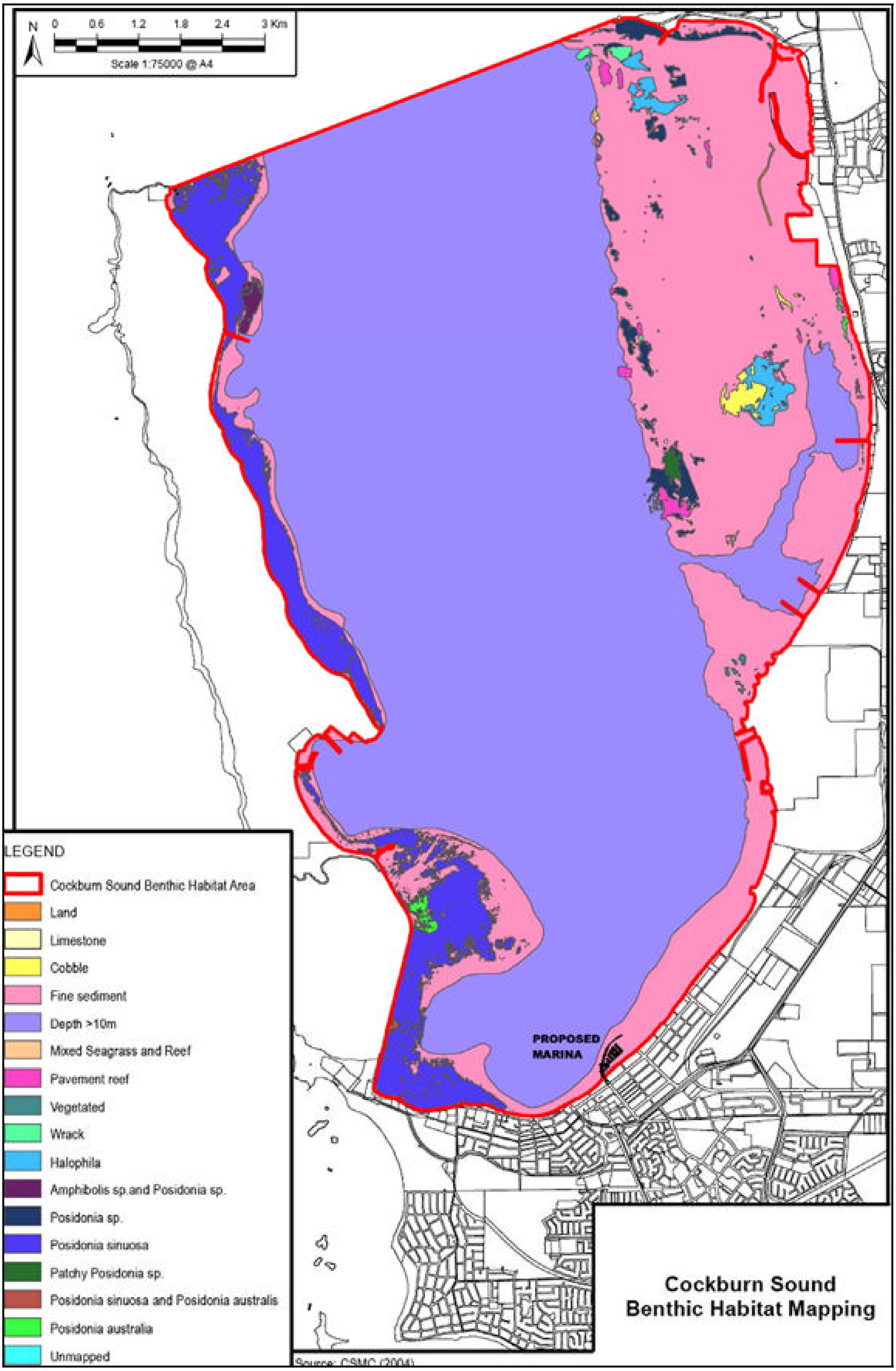
Source: Strategen (2012)

Figure 4. Benthic habitat map of Cockburn Sound



Source: DAL Science and Engineering et al. (2004)

Figure 5. Benthic habita map of the Cockburn Sound southern flats and Garden Island



Source: EPA (2009)

Figure 6. Benthic habitat map of Cockburn Sound

3. Methods

3.1. Benthic Habitat Mapping

As part of the benthic habitat mapping study an initial remote sensing analysis of available satellite imagery was undertaken. The following sections outline the methods associated with this component of the study.

3.1.1. Habitat Classes

Habitat mapping classes (Table 1) were defined based on benthic communities observed, identified and mapped during previous field observations and mapping studies (DEP 1996, RPS 2009, Strategen 2012), at a scale appropriate for the modelling of the habitats via satellite/aerial imagery. No 'reef' or other hard substrates (e.g. cobbles/boulders) were mapped as part of this study. Limestone reef pavement has been previously mapped on the eastern shoreline of Cockburn Sound, though not within the project area at Garden Island. The seawall structures within and adjacent to Careening Bay do provide some hard substrate for potential colonisation by BPPH; however, these were not mapped as part of this study. In general, the seabed at a depth greater than 10 m was not mapped as part of this study, with previous studies indicating that these depths are characterised by fine sediment with no BPPH (Figure 3, Figure 4 and Figure 6).

Table 1. Habitat mapping classes

Habitat class	Definition and key characteristics
Seagrass	Seagrass meadows comprised primarily of *Posidonia* species (i.e. *Posidonia sinuosa* and *Posidonia australis*) and occasional *Amphibolis* spp. patches
Sand (nearshore seabed)	Fine/medium grain bare sand within the nearshore coastal area (generally <10 m water depth) capable of supporting seagrass communities
Sand (offshore seabed)	Fine/medium grain bare sand within the offshore coastal area (generally >10 m water depth) incapable of supporting seagrass communities

3.1.2. Habitat Boundaries

Polygons representing the distribution and boundaries of the defined habitat classes were created through an analysis of available multispectral satellite imagery. This technique, along with the subsequent ground-truthing habitat point data, allowed for the delineation and thematic classification of defined benthic habitats derived from the spectral reflectance of the multispectral images (Mishra et al. 2006).

A search of available imagery archives was undertaken for appropriate multispectral imagery (i.e. good light penetration, low glint and low cloud cover). An appropriate image as close to the present day was selected to control for any seasonal or temporal variation in BPPH distribution between the imagery period and the proposed date for the ground-truthing survey. The type, source and properties of the acquired image are outlined in Table 2.

Table 2. Remote sensing imagery utilised for the study

Period	Type and source
February 2015	DigitalGlobe WorldView-2 Imagery, captured 26/02/2015 (0.5 m panchromatic and 2.0 m multispectral (4-band) resolution)

In addition to the benthic habitat data collected during the baseline survey, other data sources were used to assist in delineating the habitat boundaries. These were:

1. bathymetry 'admiralty' charts of the project area (Government of Western Australia Department of Transport Nautical Chart)
2. benthic habitat information from previous studies and surveys within Cockburn Sound (DEP 1996, RPS 2009, Strategen 2012, DAL Science and Engineering et al. 2004).

The following steps were undertaken during the habitat mapping process:

- The satellite and aerial imagery was sourced for the project area of interest (Table 2).
- An 'unsupervised' image classification, using PCI Geomatica Focus software, was undertaken on the WorldView-2 satellite image to create a raster of habitat distribution clusters. An unsupervised ISODATA clustering method was used as it provided the most reproducible results.
- The raster was vectorised to create topological polygons as an ESRI shapefile.
- Following the collection of the benthic habitat point data from the field survey, a marine scientist manually checked the accuracy of the modelled habitat boundaries against the ground-truthed habitat data and reclassified the thematic classifications (where necessary) in ArcMap.
- Finescale refinements of the classifications and habitat boundaries were made and the subsequent maps exported for presentation in this report.

Though visible within the aquired satellite imagery, the seabed on the western side of the causeway and western side of Garden Island were not mapped as part of this study.

3.2. Benthic Habitat Survey

3.2.1. Equipment

The subtidal benthic habitat was surveyed using the GO Visions™ Habitat Assessment System and a towed camera method (Figure 7 and Figure 8). The individual components of the system are described below.

- The GO Visions™ software allowed image analysis and habitat classification-trained marine scientists to assign and record geo-referenced habitat data in real-time (i.e. as the images were captured). For each second of recorded video, an analyst assigned a semi-quantitative habitat data value to the observed benthic habitat being viewed in real-time. The habitat point data recorded using the software were defined using a hierarchical benthic habitat classification scheme (Appendix A).
- A low-light video camera with automatic white balance and colour correction was mounted facing forward on the towed camera frame.
- An 18-megapixel DSLR camera was mounted facing downwards on the towed camera frame. The GO Visions™ Topside Control Unit (TCU) controlled the DSLR unit at the surface and the images were reviewed for real-time analysis.
- A Differential Global Positioning System (DGPS) was used to track the position of the towed camera frame. The GPS data were encoded to the habitat data, video footage and still images.
- Geo Oceans used the GO Visions™ TCU, GO Visions™ software and real-time GIS software (ArcMap) and available existing data (e.g. satellite imagery, transect locations and bathymetric charts) to assist with navigation around the survey areas and between transect locations. This also enabled in-situ survey planning and placement of new or amended transects when required.
- Bathymetry from a single beam echo-sounder was captured and corrected for Lowest Astronomical Tide (LAT) using the GO Visions™ software.

3.2.2. Survey Timing

The benthic habitat mapping survey was undertaken on 2 May 2015 onboard the *MV Lini* survey vessel (Figure 9 and Figure 10).

3.2.3. Survey Design

A total of 19 transects were surveyed within the study area (Figure 11 and Figure 12). Transects ranged in depth from 1 m and 15 m and in length from approximately 100 m to 1.3 km.

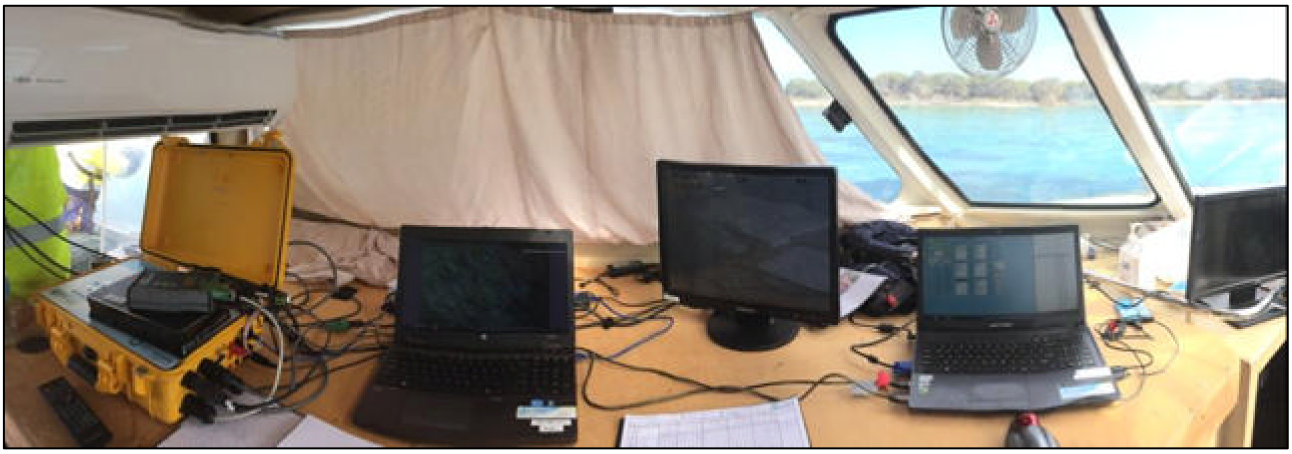
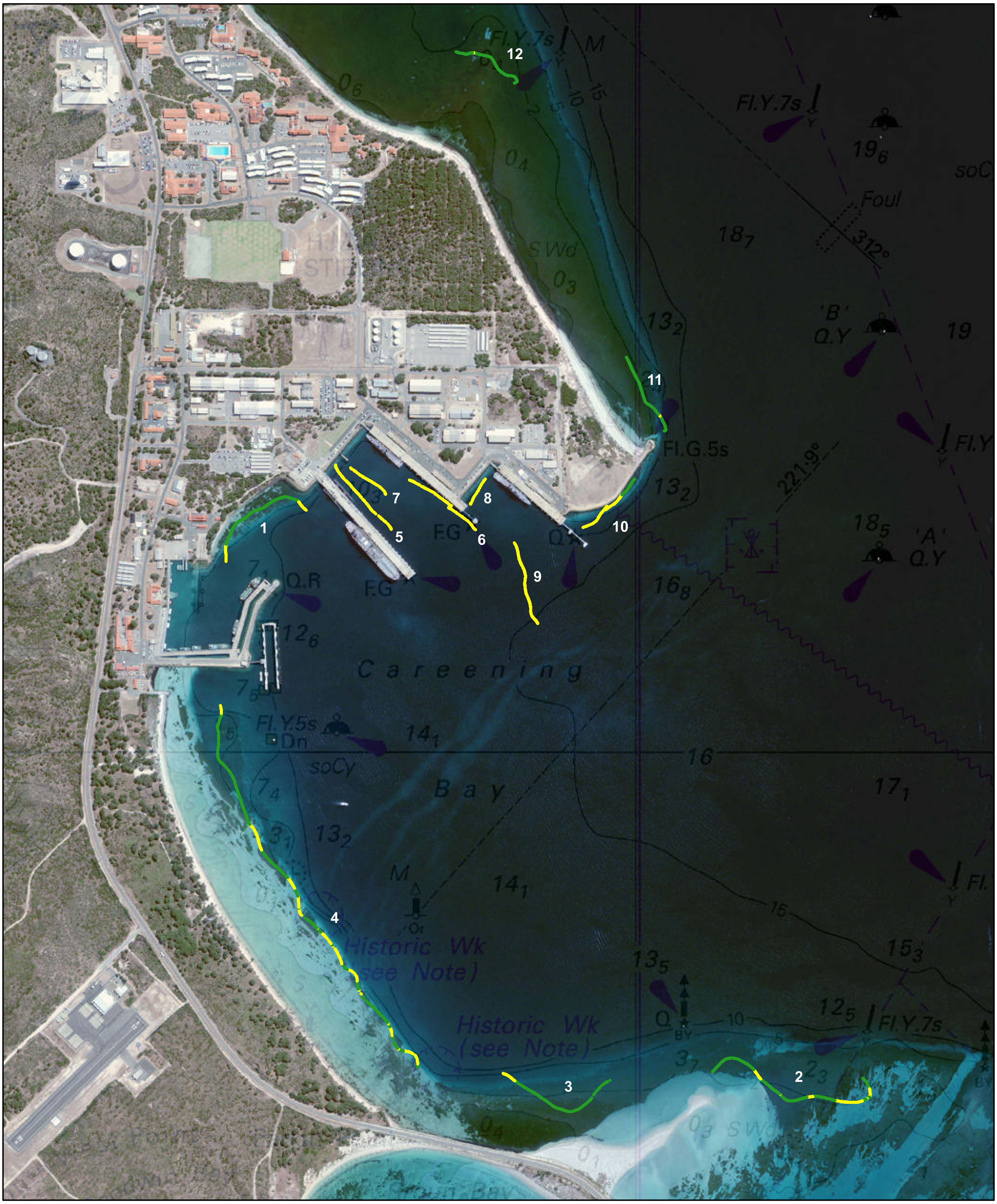


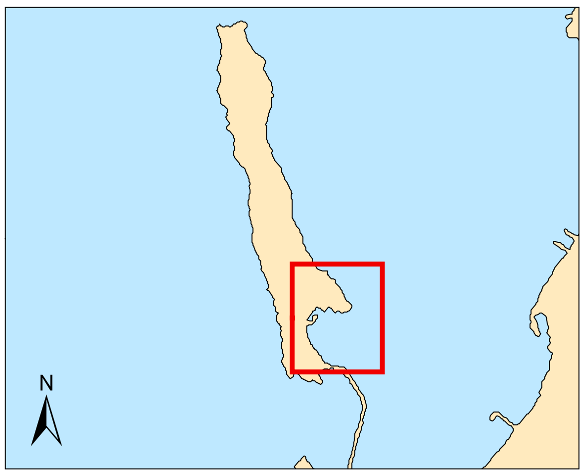
Figure 7. GO Visions™ Habitat Assessment System setup on vessel

Figure 8. GO Visions™ towed camera system

Figure 9. Towed camera deployment via the vessel's deck crane

Figure 10. Survey vessel *MV Lini*





Legend

Seagrass Presence

- Present
- Absent

Imagery Source: DigitalGlobe WorldView-2. Archive Captured – 26th February 2015. 0.5m Panchromatic and 2m Multispectral Resolution

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H.M.A.S Stirling Maintenance Dredging
Careening Bay
Benthic Habitat Point Data

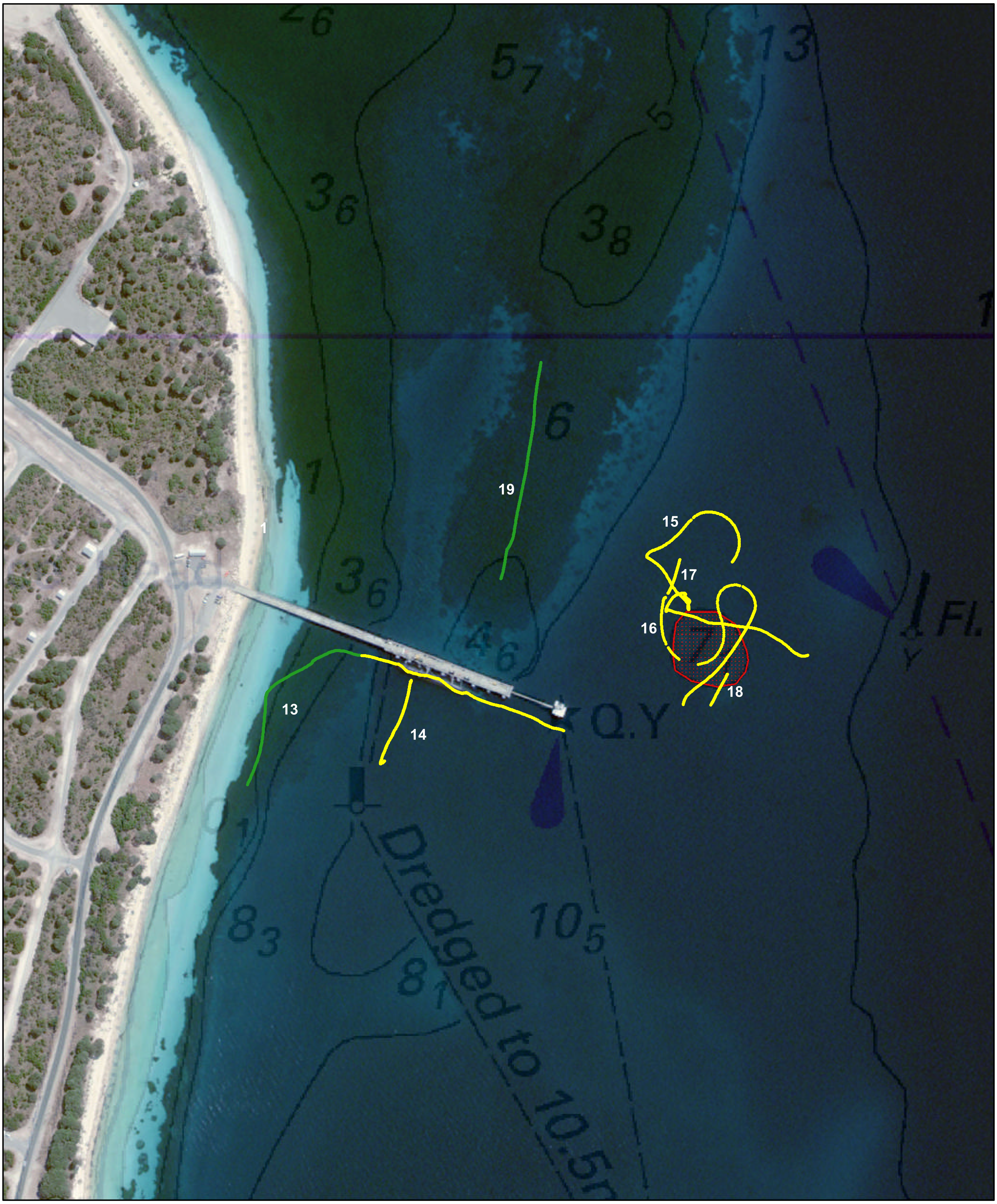
0 100 200 300 400 500 m

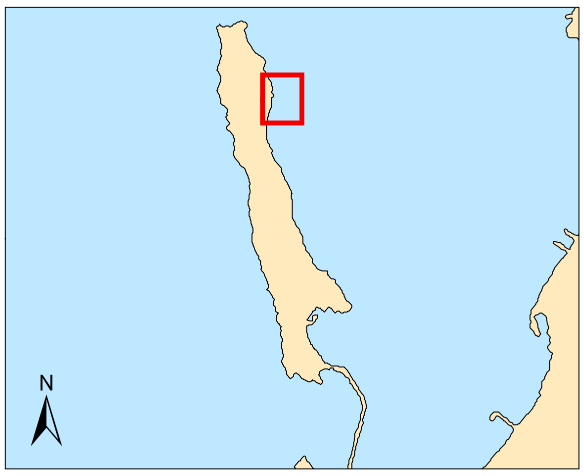
WGS 1984 Web Mercator Auxiliary Sphere
Projection: Mercator Auxiliary Sphere
Datum: WGS 1984

N

DOTAUGMAP
06/05/2015_AL
10,739 @ A3

Figure 11





Legend

Seagrass Presence

- Present
- Absent
- Existing Spoil Ground

Imagery Source: DigitalGlobe WorldView-2. Archive Captured – 26th February 2015. 0.5m Panchromatic and 2m Multispectral Resolution

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Department of Defence
H.M.A.S Stirling Maintenance Dredging
Armament Wharf
Benthic Habitat Point Data

0 50 100 150 200 m

WGS 1984 Web Mercator Auxiliary Sphere
Projection: Mercator Auxiliary Sphere
Datum: WGS 1984

N

DOTAUGMAP
07/05/2015_AL
4,807 @ A3

Figure 12

4. Results and Discussion

The BPPH observed during the field survey and mapped as part of this study were dominated by *Posidonia* seagrass (*Posidonia sinuosa* and *Posidonia australis*) (Figure 13, Figure 14 and Figure 15) interspersed by occasional patches of *Amphibolis antarctica* seagrass, particularly within the beds immediately north of the Armament Wharf (Figure 16). This outcome was expected, based on the findings of previous studies of benthic habitats within Cockburn Sound and near Garden Island (Section 2). A narrow band of sand (Figure 17) fringed the landward extent of the seagrass beds, with the deeper (>10 m) seabed characterised by fine sediment with no BPPH (apart from occasional microphytobenthos) evident (Figure 18).

Within Careening Bay, a narrow band of discontiguous *Posidonia* seagrass patches fringed the shallow nearshore area, with a larger patch evident immediately south of the southernmost jetty (Figure 26). A large bommie with encrusting favid hard coral colonies was also observed in this area. The substrate within the deeper (>10 m) parts of the bay were characterised by bioturbated fine sediment with no BPPH evident (Figure 18).

Within the Armament Wharf area, a narrow band of *Posidonia sinuosa* seagrass was observed and mapped south of the wharf, with an extensive seagrass bed mapped north of the wharf, extending to the northern most end of the island (Figure 27).

Transects towed over the existing dredge spoil ground location indicate that the area does not contain any BPPH (Figure 12 and Figure 27), with rubble and bare fine sediment observed (Figure 19 and Figure 20).

The only BPPH observed and mapped within the proposed dredge areas within Careening Bay (Figure 28) and Armament Wharf (Figure 29) was occasional microphytobenthos, with no seagrass noted within these areas (Figure 21, Figure 22, Figure 23, Figure 24, Figure 25).

Figure 13. *Posidonia sinuosa* seagrass within the survey area

Figure 14. *Posidonia australis* seagrass within the survey area

Figure 15. Mixed *Posidonia* seagrass bed (Left: *Posidonia australis,* Right: *Posidonia sinuosa*)

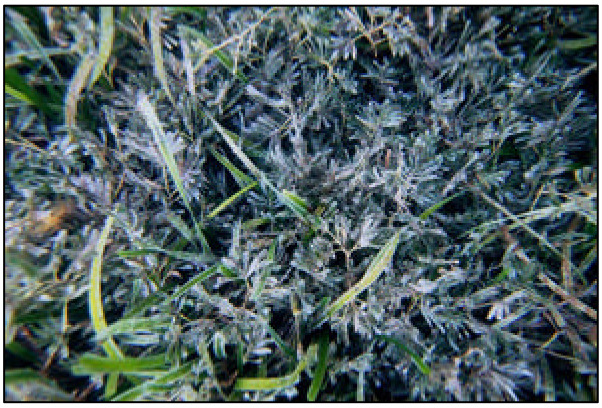


Figure 16. *Amphibolis antarctica* seagrass interspersed within a *Posidonia australis* seagrass bed

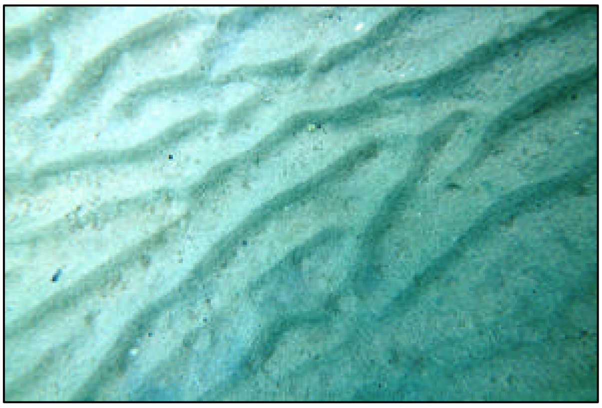


Figure 17. Sand substrate at Careening Bay

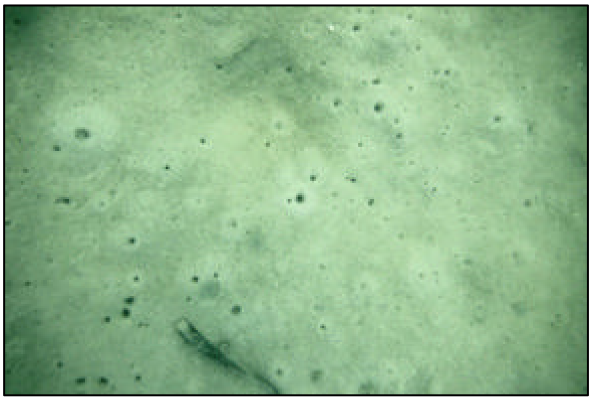


Figure 18. Fine sediment with bioturbation within deeper (>10 m) seabed areas

Figure 19. Rubble/cobble substrate within the existing spoil ground adjacent to Armament Wharf

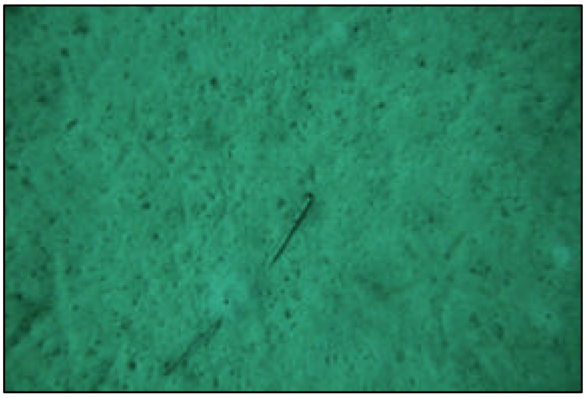


Figure 20. Fine sediment within the approximate location of the dredge spoil ground

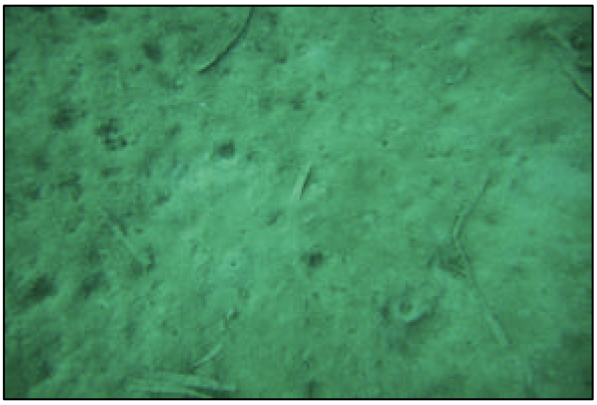


Figure 21. Fine sediment with microphytobenthos within Dredge Area A

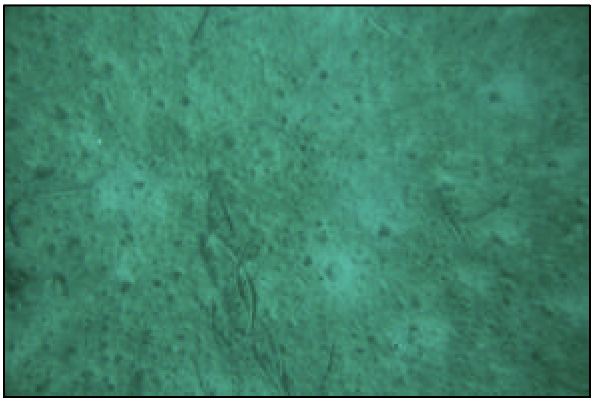


Figure 22. Fine sediment with microphytobenthos within Dredge Area B

Figure 23. Fine sediment with microphytobenthos within Dredge Area C

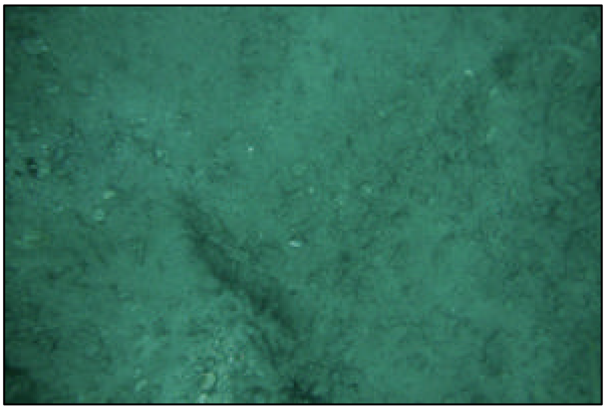


Figure 24. Fine sediment with shell fragments within Dredge Area F

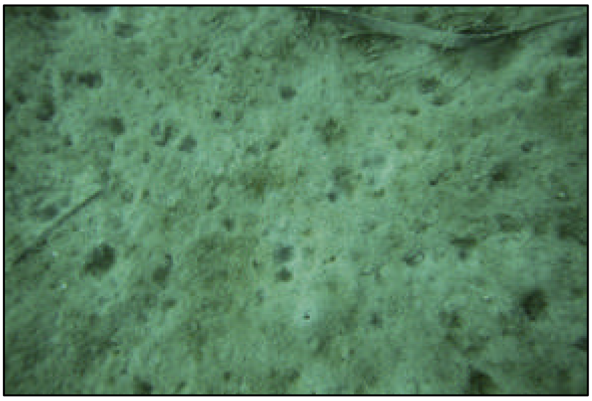
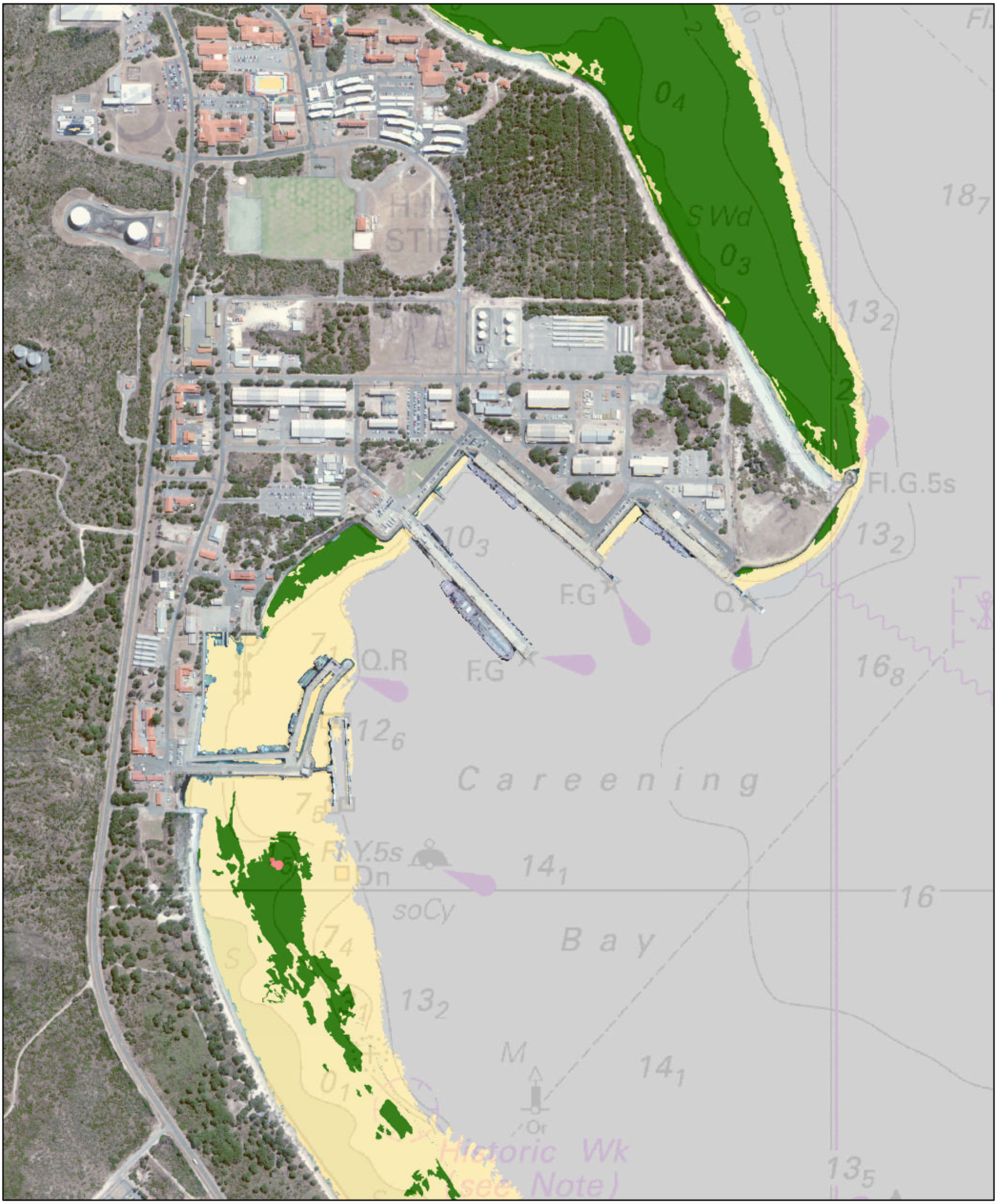
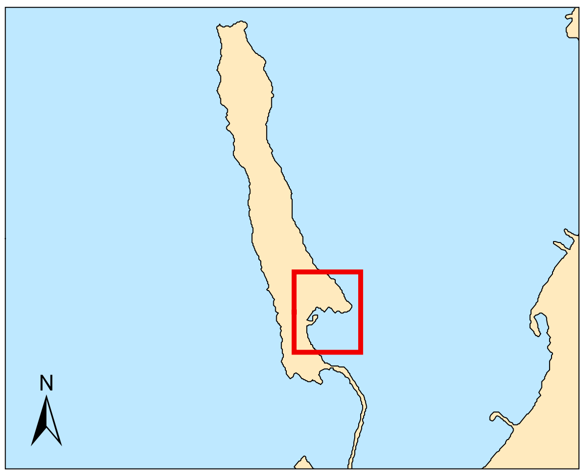


Figure 25. Fine sediment with microphytobenthos within Dredge Area G





Legend

BPPH Classes

- Seagrass communities
- Sand (<10m)
- Fine Sediment (>10m)
- Coral Bommie

Imagery Source: DigitalGlobe WorldView-2. Archive Captured – 26th February 2015. 0.5m Panchromatic and 2m Multispectral Resolution

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Department of Defence
H.M.A.S Stirling Maintenance Dredging
Careening Bay
BPPH Map

0 100 200 300 400 m

WGS 1984 Web Mercator Auxiliary Sphere
Projection: Mercator Auxiliary Sphere
Datum: WGS 1984

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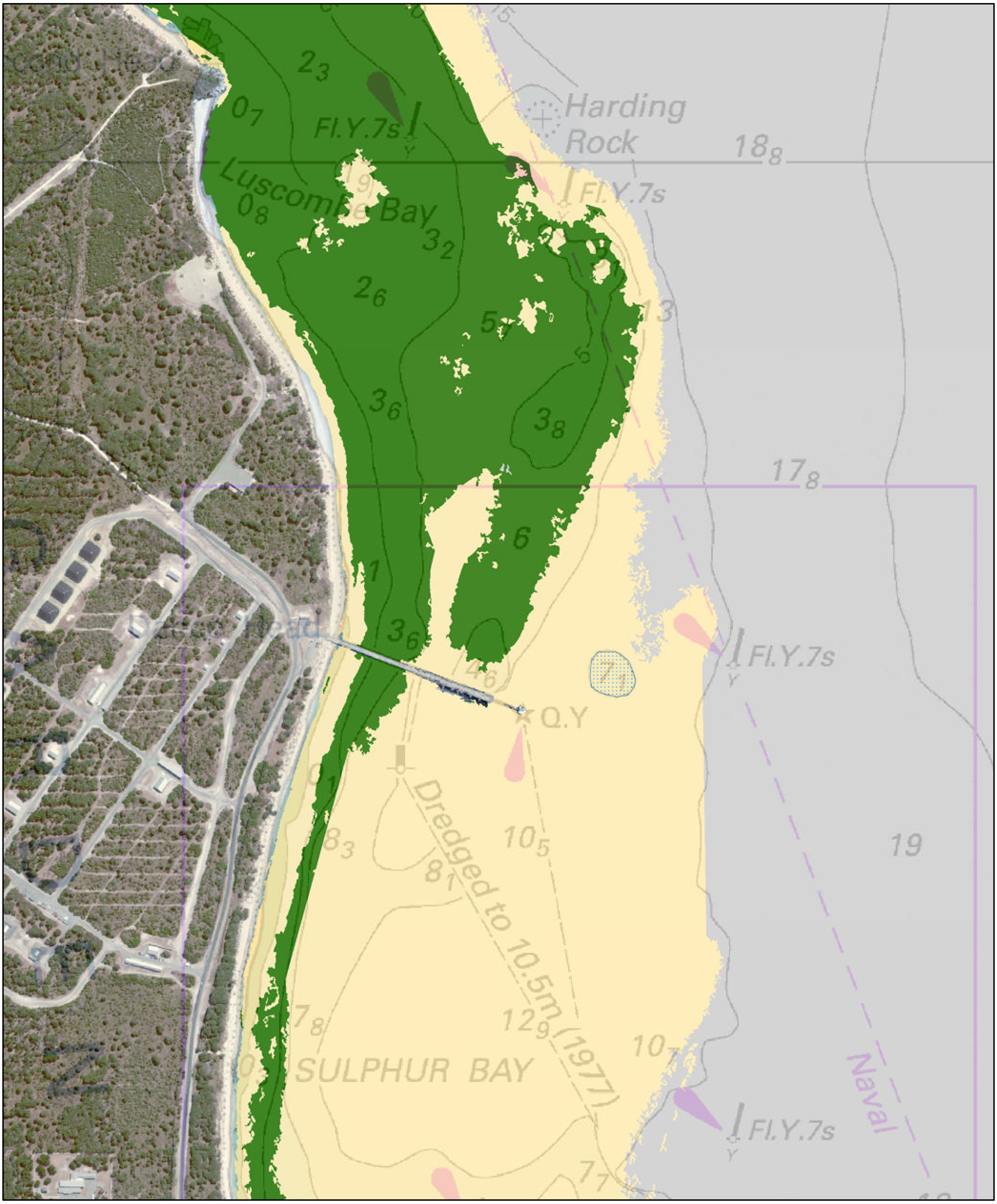
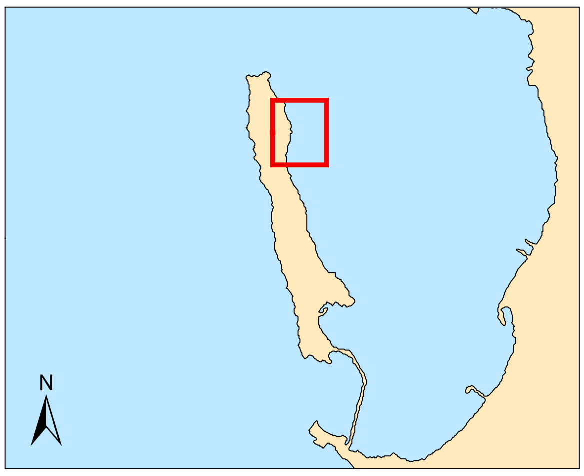
DOTAUGMAP
12/06/2015_AL
8,000 @ A3

Figure 26





Legend

Existing Spoil Ground

BPPH Classes

- Seagrass communities
- Sand (<10m)
- Fine Sediment (>10m)

Imagery Source: DigitalGlobe WorldView-2. Archive Captured – 26th February 2015. 0.5m Panchromatic and 2m Multispectral Resolution

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Department of Defence
H.M.A.S Stirling Maintenance Dredging
Armaments Wharf
BPPH Map

0 100 200 300 400 500 m

WGS 1984 Web Mercator Auxiliary Sphere
Projection: Mercator Auxiliary Sphere
Datum: WGS 1984

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DOTAUGMAP
05/06/2015_AL
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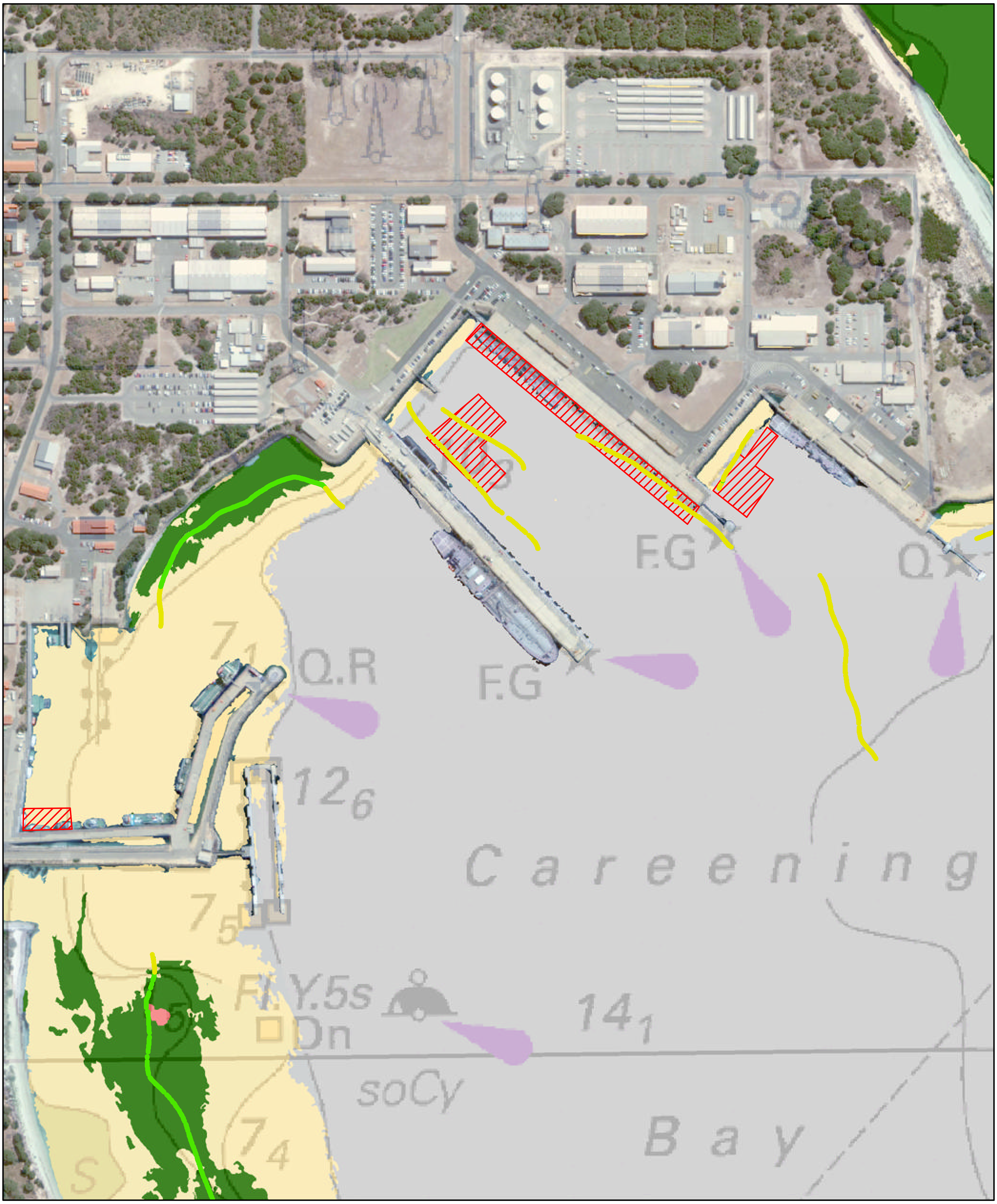
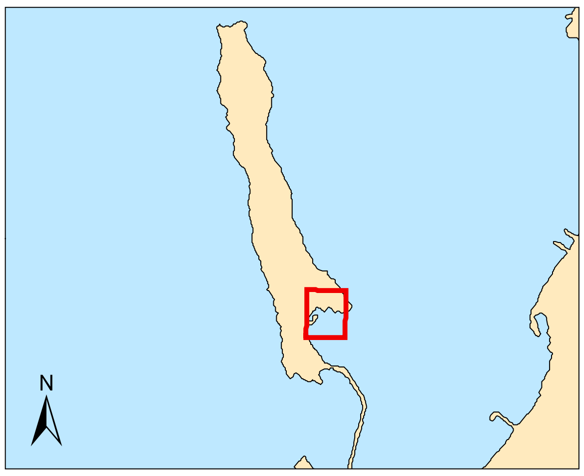
Figure 27





Legend

Proposed Dredge Areas

BPPH Classes

- Seagrass communities
- Sand (<10m)
- Fine Sediment (>10m)
- Coral Bommie

Seagrass Presence

- Present
- Absent

Imagery Source: DigitalGlobe WorldView-2. Archive Captured – 26th February 2015. 0.5m Panchromatic and 2m Multispectral Resolution

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Department of Defence
H.M.A.S Stirling Maintenance Dredging
Careening Bay
Dredge Areas BPPH Map

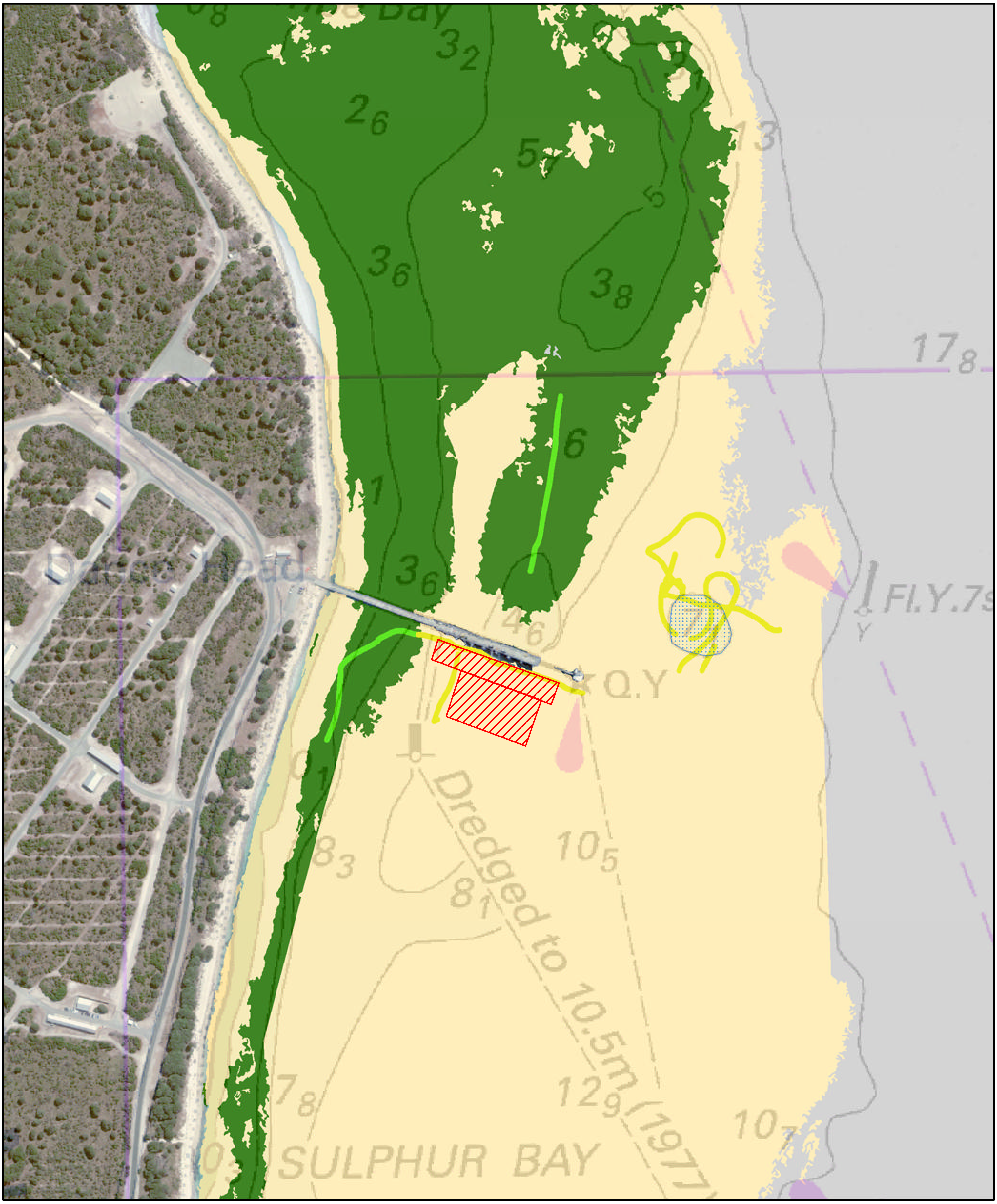
0 50 100 150 200 m

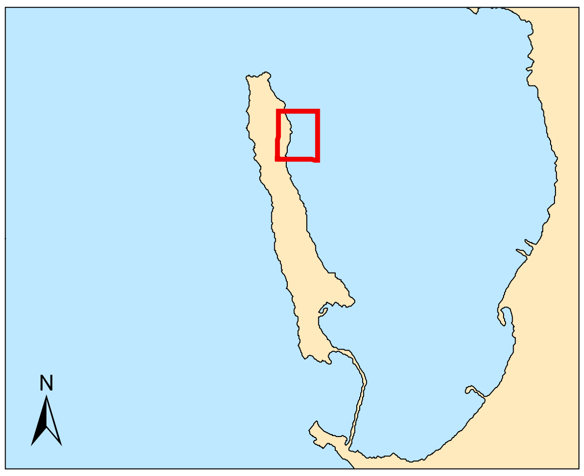
GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

N

DOTAUGMAP
05/06/2015_AL
3,974 @ A3

Figure 28





Legend

- Proposed Dredge Areas
- Existing Spoil Ground

BPPH Classes

- Seagrass communities
- Sand (<10m)
- Fine Sediment (>10m)

Seagrass Presence

- Present
- Absent

Imagery Source: DigitalGlobe WorldView-2. Archive Captured – 26th February 2015. 0.5m Panchromatic and 2m Multispectral Resolution

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H.M.A.S Stirling Maintenance Dredging
Armaments Wharf
Dredge Areas BPPH Map

0 50 100 150 200 m

GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

N

DOTAUGMAP
12/06/2015_AL
5,023 @ A3

Figure 29

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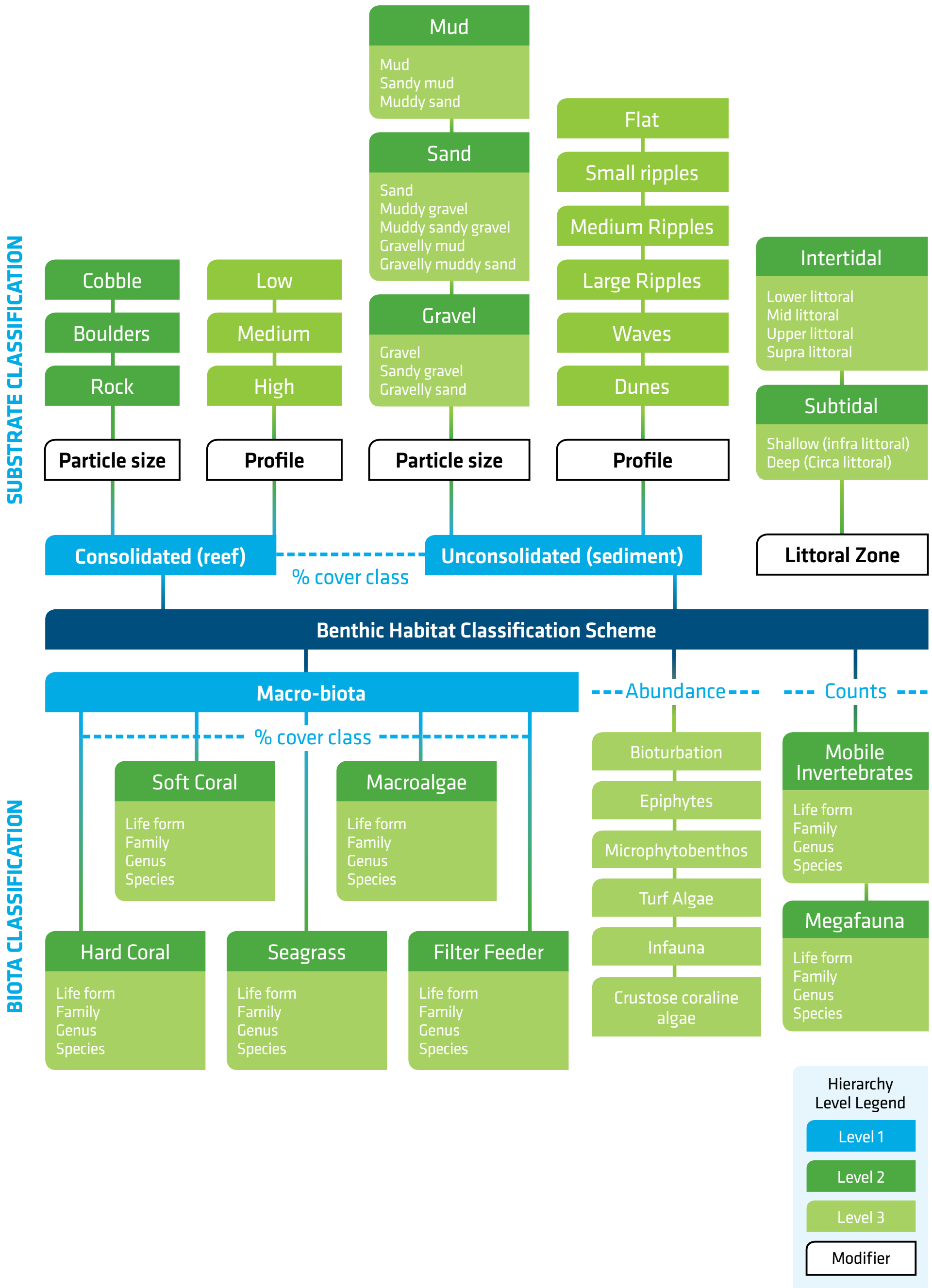
Appendix A – Geo Oceans Benthic Habitat Classification Scheme



Appendix C
Ecology of the Little Penguins of Garden Island

Ecology of Little Penguins in the Perth metropolitan region, with particular reference to the colony on Garden Island

Final Report

Prepared for Aurecon Australasia Pty Ltd

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Summary

Little Penguins from both Penguin and Garden Islands lay eggs from April-November, can raise chicks though to January, and undertake their 2-3 week long moult any time from December to February. They depart the colony before sunrise, and return around sunset, or later. Both parents are involved in incubating eggs and raising the chicks. During incubation, one parent can remain at sea foraging for >5 days, but they generally return to the nest each evening when raising chicks.

An estimated 500-600 Little Penguins inhabit Garden Island. Penguins from the main colony at the Small Boats Harbour on Garden Island foraged in Cockburn Sound when incubating eggs, including Sulphur Bay. When feeding chicks they foraged in the southern half of Cockburn Sound. When they departed the colony before sunrise, they headed almost directly eastwards from the Small Boats Harbour (south of Diamantina wharf), and spent an average of 106 minutes in this directional movement but only covered an average of 5 km. When they returned in the evening, the penguins tended to gather a few hundred metres offshore, in the area adjacent to, and extending approximately 200m past, the Diamantina wharf.

Some Little Penguins from Penguin Island foraged in Cockburn Sound during breeding. They foraged across the entire embayment during the incubation period, but used the northern half when feeding chicks. Sulphur Bay was used by some penguins during both stages of breeding.

Marine based operations in both Careening and Sulphur Bay will have the least likely impact on the penguins from both colonies if undertaken in February- March. Regardless of time of year, operations in Careening Bay should be limited to one hour after sunrise and one hour before sunset, and from evening Civil Twilight to morning Civil Twilight, i.e throughout the night, in Sulphur Bay if dredging is required to be undertaken between April and January.

1. Introduction

The aim of this report is to:

1) describe ecological parameters for Little Penguins on Garden Island in relation to marine based operations in Careening and Sulphur Bays, in particular:
   a) the known location of nesting sites
   b) the abundance of the colony
   c) their annual cycle
   d) their daily cycle
   e) areas used for travelling from, and to, the main colony in the Small Boats Harbour
   f) foraging habitat in Cockburn Sound
   g) periods when the penguins are least prone to disturbance from marine-based operations in Careening and Sulphur Bays; and
2) describe ecological parameters for Little Penguins on Penguin Island in relation to marine based operations in Sulphur Bay, in particular:
   a) annual and daily cycle, where different to that of the Garden Island penguins
   b) foraging habitat in Cockburn Sound during incubation and chick rearing, and
   c) periods when penguins are least prone to disturbance from marine-based operations in Sulphur Bay

The report also highlights the importance of the Garden Island colony for the long term presence of Little Penguins in the Perth Metropolitan region.

2. Ecology of Little Penguins

2.1 Colonies of Little Penguins on Garden and Penguin islands in context: Distribution of Little Penguin populations in Western Australia

Little Penguin (*Eudyptula minor*) colonies are typically located on islands. In Western Australia, their distribution extends from Carnac Island, 10 km south west of Fremantle, through to the Recherché Archipelago. The largest colony is found in the Perth metropolitan region on Penguin Island. Using Mark-Recapture analysis, the size of this population during the breeding season was estimated to be between 2000-2400 penguins (Cannell *et al.*, 2011). Within the Perth metropolitan region, Little Penguins are also found on Garden and Carnac islands. Outside the Perth metropolitan region, the next closest colony is found on St Alouarn Island, south east of Cape Leeuwin and approximately 300 km following the coast from Penguin Island (Cannell, 2001). The nearest colony of comparable size to that on Penguin Island is found on Cheyne Island, approximately 100 km north east of Albany and approximately 700 km south east from Perth (Cannell, 2001).

2.1.1 Conservation status of Little Penguins in Perth

Little Penguins in the Perth metropolitan region have the highest relative threat and the highest conservation value of all marine fauna in the same region (Department of Conservation and Land

Management 2003). Furthermore, the W.A. population was identified to be 'at risk' and 'subpopulations, groups or individuals at risk' from recreational interaction (Simpson and Holly 2003). The Little Penguins on Penguin Island have the highest conservation status of all major Little Penguin colonies in Australia (Dann *et al.*, 1996)

2.2 Current knowledge of ecology of Little Penguins at Garden Island

The colony on Garden Island mainly inhabits the rockwall in the Small Boats Harbour on the western side of Careening Bay, and at the Slipway. A smaller nesting area is found at Colpoy's Point, and in various sites in the rockwall between Diamantina and Parkes wharves, Parkes and Oxley wharves, and Oxley Wharf and Colpoy's Point (Fig. 1). Additionally the penguins nest in suitable habitat under some large trees at Colpoy's Point (Fig. 1).

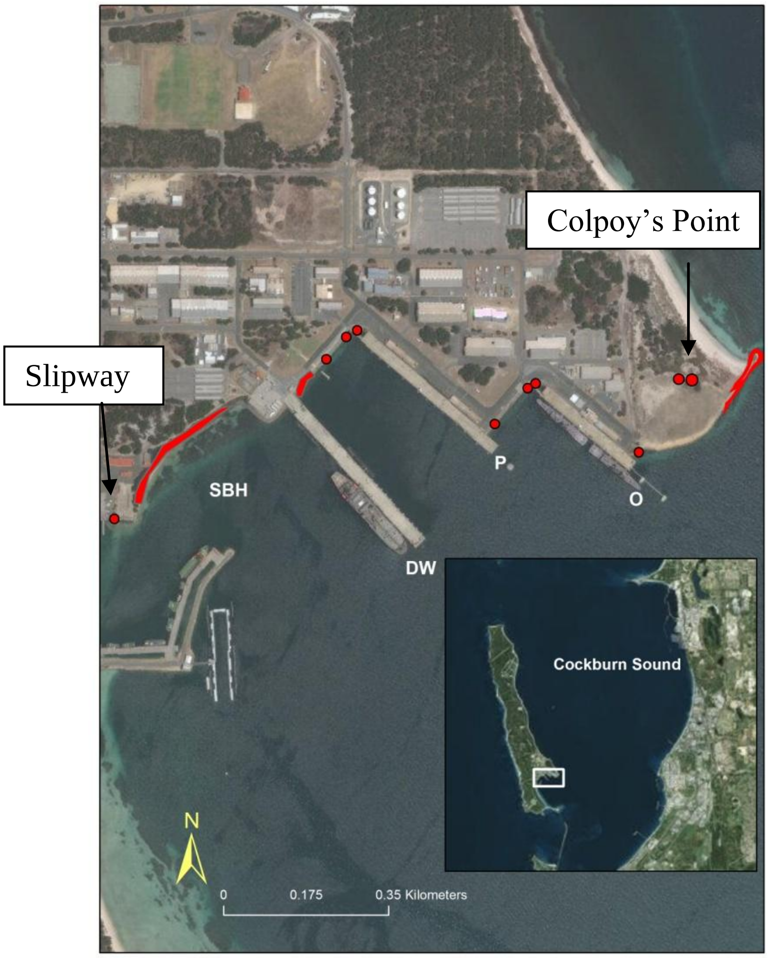

Fig. 1 From left to right- Location of nesting sites at the Slipway; rockwall in Small Boats Harbour (SBH); between Diamantina (DW) and Parkes (P) wharves, between Parkes and Oxley (O) wharves, at Colpoy's Point. Inset: map of Garden Island with the extent of the larger map highlighted by a white rectangle.

2.2.1 Abundance of Little Penguins

Currently, there are approximately 140-160 known pairs of breeding penguins on Garden Island (Cannell unpubl. data), but this does not include counts of penguins that could be nesting in other sites around the perimeter of the island. In addition, a population is composed of breeding and non breeding adults, as well as juvenile birds. Including these latter two groups of penguins in a study at Phillip Island, the total population size was found to nearly double (Sutherland pers. comm.). Providing this ratio of breeding to non breeding penguins is consistent between colonies, the total size of the colony in the areas that are monitored on Garden Island is estimated to be 500-600 individuals. However this estimate does not account for unknown numbers of penguins nesting in other sites around the island.

2.2.2 Annual cycle

Little Penguins on Garden Island breed asynchronously, i.e. they do not all breed at the same time. Consequently, eggs are laid from April to November, and the penguins can lay two clutches in a year. The number of pairs laying two clutches varies annually. First clutches are generally laid from April to August, with fewer first clutches laid in September-November. The peak of first clutches varies but usually occurs in June, and almost 2/3 of the first clutches are laid before July (Cannell unpubl. data). The peak of second clutches is usually laid in September.

For all Little Penguins, each clutch generally consists of two eggs, rarely is only one egg laid. The eggs are incubated for an average of 36 days (Stahel & Gales, 1987). Both parents share incubation, with the partners swapping every 3-5 days on average (Chiaradia & Kerry, 1999). However, longer incubation shifts do occur and appear to be related to lower food availability (Cannell unpubl. data). Once the eggs hatch, the chicks are guarded constantly for 2-3 weeks. Both parents share the guard phase, and whilst one parent guards the chicks in the nest, the other goes to sea to forage. That parent returns to the nest in the evening, feeds the chicks, and the next day the parents swap roles. Chicks are raised for an average of eight weeks, hence chicks can be present in the colony in January. After fledging at around eight weeks, the chicks depart the nest and return to the colony 2-3 years later.

It is possible for a pair of penguins to successfully raise chicks from two clutches within a year, but this is dependent on the amount of prey available.

After breeding, the adult penguins moult, and at Garden Island, this occurs any time between November and February. This is a critical process which the penguins must undergo every year. The moult takes 2-3 weeks, during which they replace all their feathers. The penguins are confined to land during the moult period as they are not waterproof.

In February and March there are fewer penguins regularly returning to the colony at Garden Island.

2.2.3 Daily cycle

Penguins leave the colony before dawn and spend the day foraging at sea. They can dive more than 100 times per hour (Ropert-Coudert et al. 2003, B. Cannell unpubl data), searching for prey. In between dives, they rest on the surface, regaining important oxygen stores. Penguins return to the colony after sunset. From monthly night counts conducted on Garden Island from May 2001-June 2003, an average of 80% of the arriving penguins came ashore within 40 minutes after sunset, and some even returned whilst it was still light (Cannell, 2003). Penguins can remain at sea overnight, and are more likely to do so if they are not feeding chicks. However, as penguins rely on vision to catch their prey (Cannell & Cullen, 1998), they tend to do very little diving at night, but remain on the surface of the water.

2.2.4 Travelling areas of Little Penguins and arrival points at the colony

Travelling areas

Data from GPS tags, deployed on Little Penguins inhabiting the Small Boats Harbour area on Garden Island (Fig. 1), indicate the penguins exhibited a highly directed movement from the colony as they departed predawn. This "departure travelling behavior" continued until approximately morning civil twilight[1]. It was characterised by a high resolution of GPS fixes, slow speeds and short distances between fixes, indicating very little time spent underwater (Cannell unpubl. data).The penguins spent an average of 106 minutes in this directional movement but covered an average of 5 km. This movement extended from the colony almost directly east (Fig. 2). Note that this data is for travelling behavior only, and does not include information on foraging habitat.

Fig. 2 The area used by penguins immediately after departure from the colony in the morning (green outline)

The behavior of the penguins as they returned to the colony was markedly different to the morning departure. The penguins tended to gather a few hundred metres offshore, in the area adjacent to, and extending approximately 200m past, the Diamantina wharf (Fig 3). The penguins remained in this area for up to an hour prior to landing at the colony. This is called "rafting" and penguins can be heard calling during this time, using a monosyllabic "quak" (Stahel & Gales, 1987), Cannell pers. obs). Their return ashore is then rapid and is distinguished by shallow dives, surfacing only to take a

[1] Morning civil twilight begins when the sun is 6° below the horizon. In the absence of any other light, large objects can be seen but no detail can be observed. The sea horizon is also clearly defined (http://www.ga.gov.au/scientific-topics/astronomical/astronomical-definitions#heading-2)

quick breath (Cannell pers. obs.). Once they arrive ashore, they remain on the beach or lower rocks of the rockwalls for some time before returning to their burrow (Cannell pers. obs.).

Fig 3. The area used by the penguins immediately prior to arrival at the colony in the evening (red outline). The penguins remained in this area for up to an hour.

Note that the data for the departure and arrival areas were not collected from those penguins nesting at the Slipway, between the wharves or at Colpoys Point. For these birds, it is likely that they would be moving directly from their nest sites, and head in an easterly to south easterly direction during departure.

Arrival points between the wharves on Garden Island

Penguins use arrival and departure points that are closest to their burrows, and have a high site fidelity to these areas (Cannell *et al.*, 2011)

In the evening of 11/10/2010, four observers using night vision equipment observed penguins coming ashore between Diamantina and Parkes Wharves, Parkes and Oxley Wharves, and Oxley Wharf and Colpoy's Point. Penguins were observed arriving at various places between the wharves (Figs. 4-7). However, even with the night vision equipment, it was not possible to determine the route they used within the water.

Since 2010, a few more nesting sites have been observed closer to Parkes and Oxley wharves. Hence it is likely that a few penguins would also be arriving and departing closer to the wharves.

Fig. 4 The areas where the penguins arrived between Diamantina Wharf and Captains Landing on 11/10/2010, as indicated by the stars

Fig. 5 The areas where the penguins arrived between Captains Landing and Parkes Wharf on 11/10/2010, as indicated by the stars

Fig. 6 The areas where the penguins arrived between Parkes and Oxley Wharf on 11/10/2010, as indicated by the stars

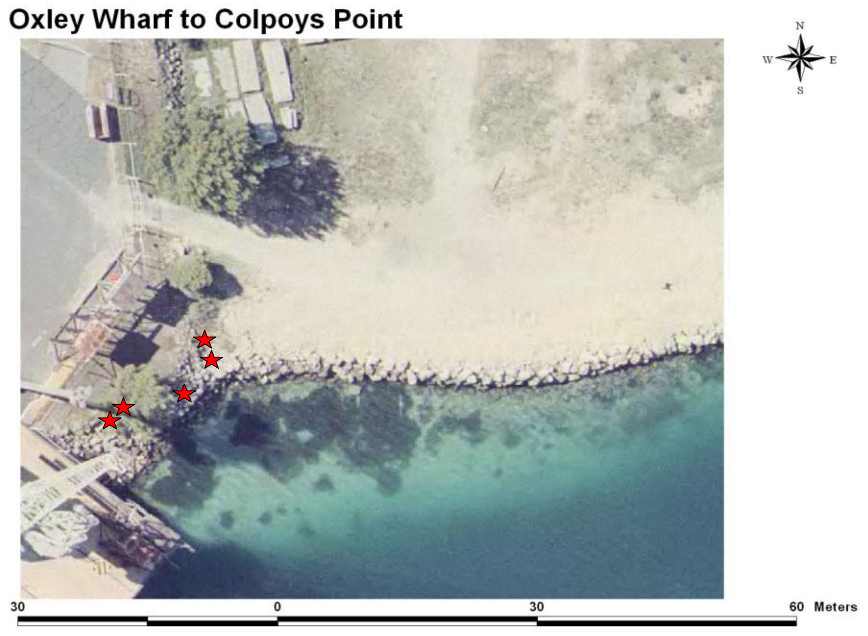

Fig. 7 The areas where the penguins moved to between Oxley Wharf and Colpoys Point on 11/10/2010, as indicated by the stars.

Even given these arrival points, it is not clear where the penguins from these nesting areas raft offshore. This is because the rafting is thought to provide a protective mechanism, whereby groups of penguins come ashore together, thereby decreasing the likelihood of a penguin interacting with a predator. Hence, raft formation may be closer to the nest sites between the wharves and at Colpoy's Point.

2.2.5 Foraging habitat of Little Penguins on Garden Island

Locations from satellite tags deployed on Little Penguins from the Small Boats Harbour at Garden Island showed that they foraged throughout Cockburn Sound whilst incubating eggs. This included Sulphur Bay (Cannell unpubl. data). They generally remained at sea for > 3 days (Cannell unpubl. data). The foraging habitat of these penguins was reduced when raising chicks, and was located in the southern half of Cockburn Sound (Cannell unpubl. data).

2.3 Current knowledge of ecology and foraging habitat of Little Penguins at Penguin Island

2.3.1 Annual and daily cycle

The annual cycle of Little Penguins on Penguin Island is similar to that for the Garden Island colony, i.e. laying eggs from April- November, some pairs laying two clutches a year, and undergoing their annual moult any time from November-February. The major difference is that fewer first clutches are laid, on average, before July (Cannell unpubl. data).

The daily cycle of Little Penguins on Penguin Island is also similar to those on Garden Island, except that penguins return later to the colony, usually returning 1-2 hours after sunset. This indicates that they are foraging further from their colony than the penguins at Garden Island.

2.3.2 Foraging habitat of Little Penguins on Penguin Island

Data from both satellite and GPS tags deployed on penguins from Penguin Island indicated that they foraged in Cockburn Sound while breeding (Cannell unpubl. data). While incubating eggs, penguins that foraged in Cockburn Sound utilized the entire embayment, including Sulphur Bay (Cannell unpubl. data). They remained within Cockburn Sound for >5 days. While raising chicks, the penguins used the northern half of Cockburn Sound, including Sulphur Bay. However, they rarely remained at sea overnight, but generally returned to Penguin Island the same evening to feed their chicks (Cannell unpubl. data).

3. Periods when penguins are least prone to disturbance from marine-based operations

3.1 Garden Island colony

Penguins utilize the marine environment from their nesting sites to their foraging grounds in Cockburn Sound. They are more likely to use these areas daily when they are breeding, i.e. from April-January. However, generally few chicks are still present in January. Moulting penguins remain within the colony until they have completed moult, then depart the colony. It is not known how long the penguins remain at sea after moulting. However, penguins infrequently return to the colony in February and March, hence these are the months when the penguins are least prone to disturbance.

On a daily basis, whether incubating eggs or raising chicks, the penguins depart before sunrise and return around sunset. Therefore, daytime operations in Careening Bay one hour after sunrise and one hour before sunset would reduce the likelihood of impact on the Little Penguins. However, for those penguins remaining at sea during incubation, and potentially foraging within Sulphur Bay, impacts associated with marine based operations would be minimised if undertaken from Civil Twilight in the evening to Civil Twilight in the morning, i.e. throughout the night, if dredging is required to be undertaken between April to January.

3.2 Penguin Island Colony

Some penguins from Penguin Island forage within Cockburn Sound during breeding, i.e. from April-January. Similar to the Garden Island colony, marine based operations undertaken during the day in February and March are the least likely to impact the penguins, however night time operations will also likely have minimal impact.

On a daily basis, some penguins from Penguin Island will potentially use Sulphur Bay for foraging during the entire breeding cycle. Therefore, as for the Garden Island colony, any impacts on the penguins that are associated with marine based operations at Sulphur Bay will be minimized if they are undertaken from Civil Twilight in the evening to Civil Twilight in the morning, i.e. throughout the night, if dredging is required to be undertaken between April to January.

4. Importance of Cockburn Sound to maintenance of Little Penguins in the Perth metropolitan region

In its current state, Cockburn Sound is likely to play a very important role in the maintenance of Little Penguins in the Perth region in the long term. This is because:

1. The penguins on Garden Island generally have a higher breeding success, (using > 10 years of breeding success data from both Garden and Penguin islands (Cannell unpubl. data);
2. A higher proportion of the Garden Island colony breeds twice a year (Cannell unpubl. data);
3. The breeding of the penguins on Penguin Island is negatively impacted by increased sea surface temperatures (Cannell *et al.*, 2012). However, this is not always so for the penguins on Garden Island, or to the impact is not as great (Cannell unpubl. data).
4. The maximum temperatures within the nest sites on Garden Island are likely to be lower than those on Penguin Island, due to the different type of habitat in which the nest sites are found (limestone rockwall compared to nests under bushes). Higher nest temperatures have been associated with reduced attendance and success (Ropert-Coudert et al. 2004)

Therefore, long term impacts associated with climate change may be greater on the Penguin Island colony than that at Garden Island, which could ultimately result in a larger population at Garden Island.

Naturally, if fish abundance in Cockburn Sound declines and mortality rates of the penguins increase, then the role that this colony will have in the long term maintenance of a population in Perth will decline.

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