

Benthic Habitat Mapping in Western Port– Desktop Review and Study Design

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In May 2016 the Special Minister of State asked Infrastructure Victoria to provide advice on the future capacity of Victoria's commercial ports. Specifically, the Minister has asked for advice on when the need for a second container port is likely to arise and which variables may alter this timeline. The Minister has also asked for advice on where a second container port would ideally be located and under what conditions, including the suitability of, and barriers to investing in, sites at the Port of Hastings and the Bay West location.

In undertaking this task, Infrastructure Victoria reviewed work that was completed as part of the Port of Hastings development project before it was cancelled in 2014. This document forms part of the initial work undertaken for the proposed port development at Hastings. Infrastructure Victoria considers that much of the previous Hastings work, although preliminary in nature, is relevant and suitable for informing a strategic assessment. Therefore, Infrastructure Victoria has made the reports previously commissioned for the development project part of the evidence base on which Infrastructure Victoria will use in providing the Minister with advice.

The opinions, conclusions and any recommendations in this document are based on conditions encountered and information reviewed at the date of preparation of the document and for the purposes of the Port of Hastings Development Project.

Infrastructure Victoria and its consultants have used the information contained in these reports as an input but have not wholly relied on all the information presented in these reports.

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1. Introduction

1.1 Context

1.1.1 Project overview

The Victorian Government has identified the Port of Hastings as a key area for port expansion. An expanded Port of Hastings will increase capacity and competition in the container ports sector servicing Melbourne and Victoria helping to manage the expected growth in container trade.

The Port of Hastings Development Authority (the Authority) and its board were established in January 2012 under the Transport Integration Act 2010. The primary objectives of the Authority are to:

- manage and operate the Port of Hastings; and
- facilitate the development of the Port of Hastings as a viable alternative to the Port of Melbourne as a container port to increase capacity and competition in the container ports sector to accommodate future growth in trade, consistent with the vision statement and the transport system objectives.

Over the next three to four years, the Authority will be working to develop a business case for an expanded Port of Hastings and undertake comprehensive environmental assessment. This business case will include:

- preferred project design/scope (including transport connections)
- necessary environmental approvals (including impact assessment)
- preferred governance and delivery strategy

In May 2014, the Port of Hastings Development Project was declared a 'Major Transport Project' under the Major Transport Project Facilitation Act 2009 (MTPF Act).

In July 2014, the then Minister for Ports, Mr David Hodgett, formally appointed the Authority as the Project Proponent under the MTPF Act.

1.1.2 Environmental and social studies

The overall design methodology for the Project involves an iterative design process which has commenced and will continue for around two years. The design process will cycle and re-cycle the evolving design through an evaluation process that allows design options to be tested and evaluated against economic, environmental, social and other objectives and associated criteria. Performance requirements will be developed as an integral part of the design process to clearly define the environmental and social outcomes that the Project must achieve in its implementation phases. The preliminary design will demonstrate the way in which the Authority considers the Project could be developed so as to achieve the performance requirements.

Environmental and social studies are required for the Project to inform the design development process and to assess the Project in accordance with the Approvals Strategy previously adopted by

the Authority. An overview of the framework for the environmental and social studies and their relationship with the design process is shown in **Figure 1**.

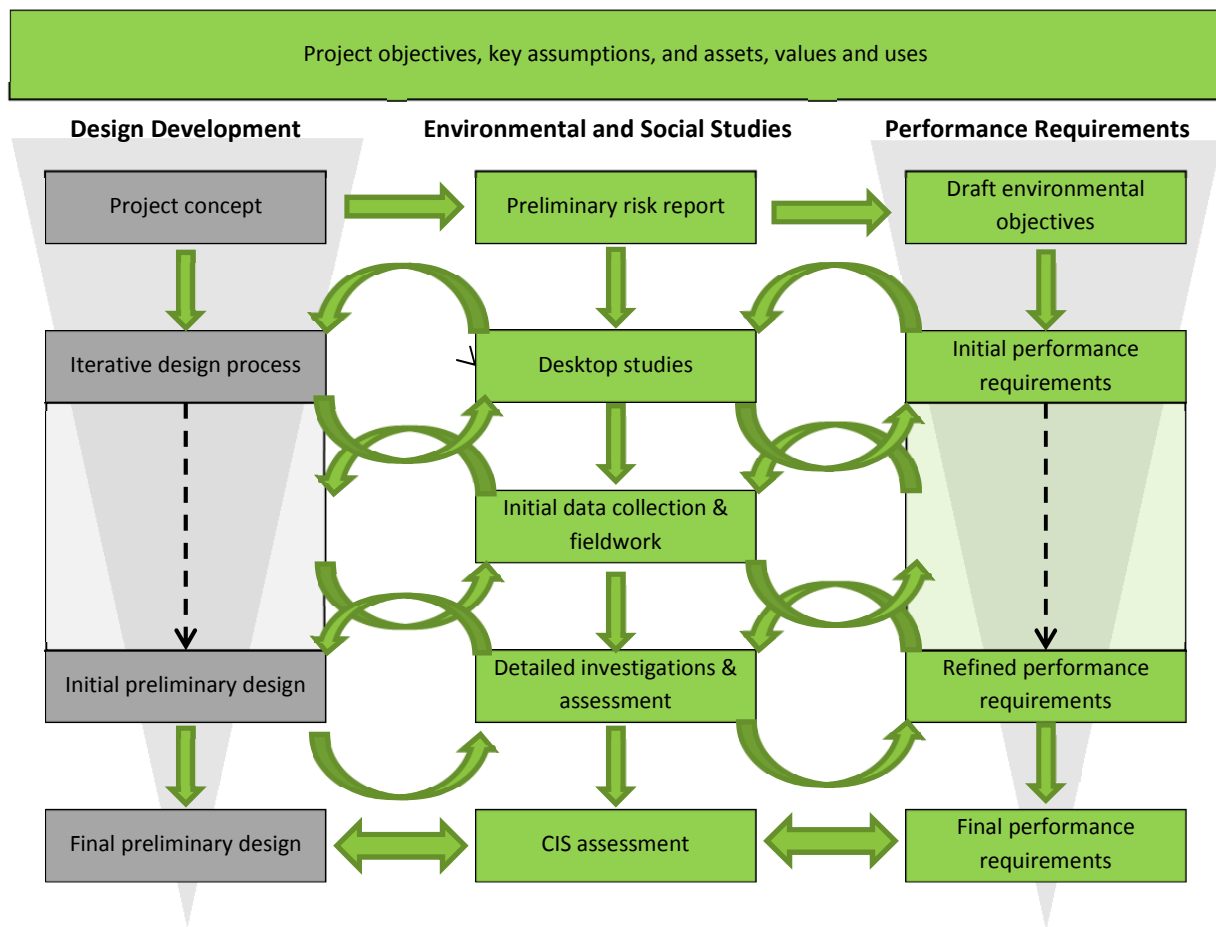


Figure 1. Framework for environmental and social studies

As shown in **Figure 1**, a stepwise approach is being employed to implement the environmental and social studies for the Project. This reflects both the iterative relationship between the studies and the design development process and their ultimate purpose of informing assessment under the *Major Transport Projects Facilitation Act 2009* (MTPF Act) and the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The key steps in the implementation of the environmental and social studies are:

- Undertake an initial assessment of need using an issues screening process to identify priorities for studies
- Initiate environmental and social investigations required to support the design development process
- Undertake desktop reviews to complete the assessment of the adequacy of existing information and confirm methodology for any further existing conditions investigations, including field work (where required)

- At the relevant stage of project definition and taking into account emerging performance requirements, undertake field and other investigations to characterise existing conditions
- Following the issue of the preliminary design, undertake risk and impact assessments to support preparation of the CIS.

1.2 Purpose and Scope

The purpose of this report is to present a desktop review of the adequacy of existing information and confirm methodology for any further existing conditions investigations, including field work (where required) for habitat mapping.

The scope of this report includes:

- Identifying the key questions to be addressed by a habitat mapping baseline study in support of investigations being completed for the Project
- Review of existing background information and historical data to identify its suitability to map habitats in support of design decision making, impact assessment, identification of relevant management and mitigation measures and development of performance criteria, and approvals requirements
- Identifying gaps in existing data or information which should be addressed to adequately inform design decisions, impact assessment, performance requirements and approvals
- Defining a habitat mapping method to address any identified information requirements.

1.3 Limitations

The contents of this document reflect Deakin University's current position on the subject matter of this document. It is provided for discussion or information purposes and is intended to be a guide only. The contents of this document should not be relied upon as representing Deakin University's final position on the subject matter, except where stated otherwise. Any views expressed by Deakin University in this document may change as a consequence of Deakin University finalising formal technical studies or specifications, or legislative, or procedure and regulatory developments. Any figures provided are indicative only, are subject to change and are dependent upon a number of factors.

2. Key Questions

2.1 Summary of Benthic Habitats in Western Port

The following section provides an overview of the marine habitats that occur in Western Port which are also identified in the Ecological Character Description for the Ramsar sites as critical ecosystem components of the site.

The Western Port embayment is an estuarine environment characterised by extensive **mudflats** (approximately one third of West Port), **saltmarsh**, **mangroves** and **seagrass** beds (IMCRA 2006). It is a large shallow bay that is divided into five interconnected basins by several islands and channel constrictions. The geography of Western Port means that strong and complex tidal currents create pathways for dispersal of benthic flora and fauna as well as movement of sediments, nutrients and toxicants (Melbourne Water 2011).

The benthic biological habitats within the bay are especially important (e.g. see Figure 2), providing many varied ecosystem services including nursery/reproduction habitat for shorebird and fish, reduction of sedimentation and carbon sequestration. Mangrove and saltmarsh are the dominant intertidal vegetation within Western Port, where the coast retains a massive area of intact saltmarsh (Boon *et al.* 2011). Within the bay there is only one mangrove species, *Avicennia marina* subsp. *australasica*, stands of which often control sedimentation patterns creating depositional mudflats (Bird 1986). Below the low tide mark, seagrass is the dominant macrophyte with four main species detected in the bay; *Zostera muelleri*, *Heterozostera tasmanica*, *Halophila australis* and *Amphibolis antarctica* (Blake & Ball 2001). Seagrasses are colonisers of mud, silt and sand and are therefore important for maintaining water quality and providing ideal habitat for fish and benthic fauna communities (Blake & Ball 2001). Linkages between fish communities and benthic habitats are among some of the most ecologically significant relationships within Western Port. This includes nursery habitat for many species and areas of high diversity, such as the south-eastern corner where diverse reef biota close to rhodolith beds and breeding areas for elephant fish form complex interdependent benthic habitats with high natural values (Melbourne Water 2011).

Intertidal mudflats and highly diverse invertebrate communities within soft sediments create an important environment for many bird species; including shorebird habitat that harbours 10000 – 15000 migratory waders, in excess of 10000 ducks and Black Swans and threatened species such as the Fairy Tern (*Cygnus atratus*) (KBR 2010). In 1982 a large portion of Western Port was classified as Ramsar wetland signifying its international importance (KBR 2010). It is due largely to the soft sediment fauna and complex vegetation communities that make these environments so ecologically important. Because of the extensive interconnected channels and bodies of shallow water coupled with strong tidal flushes, benthic habitats are particularly susceptible to critical linkages within the bay. For example the extent and penetration of marine tidal currents can be witnessed with the Crawfish Rock in the north arm, which supports a rich diversity of marine algae, filter-feeding sponges, ascidians and other sessile biota. Shepherd *et al.* (2009) displayed the vulnerability of these biological communities to disturbances from increased sedimentation and reduced water quality. The decline in water quality caused by large scale seagrass loss in the 1970s, impacted flora at Crawfish Rock resulting in a sharp decline in canopy biomass and species richness of marine algae (↓66%) over the past 35 years (Shepherd *et al.* 2009).



a. Dense seagrass, *Zostera* sp. on sand (north arm)



b. Dense sea pens on sand (north arm)



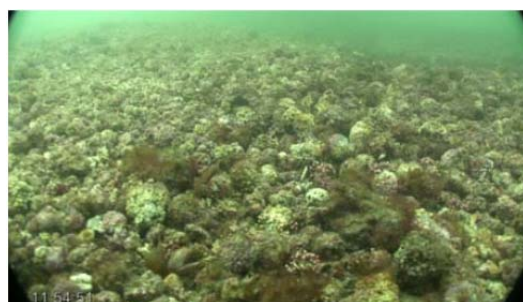
c. Sponges and gorgonians on reef (north arm)



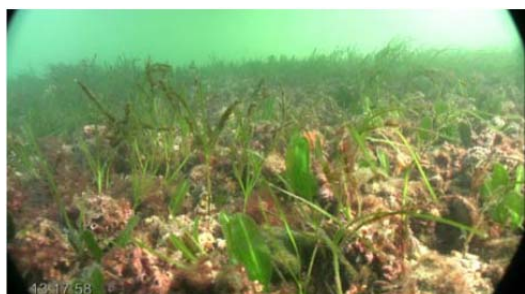
d. Bare silt with infauna burrows (north arm)



e. Bryozoans and sponges (Corinella)



f. Dense rhodolith bed (Rhyll)



g. Rhodoliths with seagrass (Rhyll)



h. Rhodoliths and mixed algae (Rhyll)

Figure 2. Example representative benthic habitats and communities in Western Port. Image still frames from groundtruth video surveys (Blake *et al.* 2013)

2.2 Key questions to be addressed

This section defines the scope of the marine habitat mapping requirements by identifying key questions that should be addressed in the review of the adequacy of existing information to describe marine habitats from a current and historical perspective in Western Port. The key questions and scope of proposed mapping investigations will provide important baseline information to support other specialist investigations including seagrass, marine fish and water quality.

1. What is currently known about Western Port benthic habitats and where are they located?
 - Geophysical mapping data
 - Subtidal habitat mapping
 - Intertidal vegetation mapping
2. What is the location and extent of areas of high biodiversity and natural value significance?
3. How can we monitor ongoing change and effects to seafloor habitats?
 - Baseline information
 - Prioritisation of monitoring sites
4. What information is available to define inter-annual and seasonal variation in key habitats?
 - Separating natural variation from impact assessments
 - What information is available to define cover of habitats at the time of its listing (1982) as a Ramsar site?

3. Information Review

3.1 Overview of existing studies

This section provides an assessment of previous habitat mapping investigations (Table 1) of critical components of the ecological character of the Western Port Ramsar site. The assessment of the relevance and data limitations are on the basis of whether they provide sufficient information to address the key questions identified in Section 2.

The relevance of these investigations have been scored as either high, medium or low. Definitions for these rankings are:

High – High quality information useful for providing a historical baseline. Methods applied allow for measures of uncertainty of data products to be assessed. Provides new knowledge on habitat types and extent.

Medium - Useful information on historical habitat extents and current status in Western Port. Limited information available to inform data uncertainty and associated area estimates the habitat mapping may provide.

Low – Provide little or no information that can be used to quantify habitat extents. May provide a historical perspective and indication of habitat loss

Table 1. Overview of previous studies pertaining to mapping and distribution of habitats in Western Port. Study scope, relevance and limitations of data types available are summarised. For “Data Limitations”, bold text denotes data types including, mapping = full coverage mapping survey datasets, groundtruth = point/transect field observations

STUDY	SCOPE	RELEVANCE	DATA LIMITATIONS**
Shapiro (1975)	Biological and geological mapping of Western Port as part of the original Western Port Bay Environmental Study. Provides broad habitat classifications (e.g. mangroves, seagrass & sediment flats) and defines areas of ecological significance.	MEDIUM - LOW Provides some historical baseline information on broad classification of benthic habitats across whole bay.	Accuracy and methodological limitations of habitat classifications. Can provide mapping and groundtruthing information if original data can be acquired.
Bulthuis (1976), (1981) and (1984) Bulthuis &	Used field data to make maps that modified the first recorded seagrass surveys in Western Port as part of Shapiro (1975).	MEDIUM Initial subtidal vegetation mapping of	Provides initial historical perspective of seagrass distributions, with mapping surveys.

STUDY	SCOPE	RELEVANCE	DATA LIMITATIONS**
Woelkerling (1983)	Estimated cover of seagrass and macrophytic algae at 250 km ² . Later, Bulthuis (1984) estimated 85% dieback in seagrass compared to the initial 1975 surveys.	Western Port. Detected seagrass diebacks.	
Bird (1986)	Used nautical charts cross-referenced with aerial photography to chart distribution of mangrove habitat and relate this to shoreline geomorphology. Determined that 40% of the mid shoreline had a mangrove fringe that varied between 40 and 300 m wide in the mid-1980s.	LOW Historical perspective on only one vegetation type (mangroves).	If data can be acquired there is potentially useful mapping information to assess changes in mangrove habitat in Western Port.
Unknown (1979)	Initial side-scan SONAR surveys of the lower eastern arm in Western Port. Products include geomorphology habitat map of sediment and clay forms.	LOW First recorded side-scan SONAR of the east arm main channel.	Accuracy and detailed methodology of habitat maps and mapping data products not known. Potential to examine historical change in seagrass extent for section of the eastern arm if historical ground data can be located for verification.
Shepherd <i>et al.</i> (1989)	Shepherd <i>et al.</i> (1989) defined seagrass distributions between the mid-1970s and 1989 describing a habitat loss from 250 km ² to 72km ² , especially <i>Zostera</i> sp. in northern and eastern Western Port.	MEDIUM - LOW Historical perspective on seagrass (Shepherd <i>et al.</i> 1989).	Shepherd <i>et al.</i> 1989 can provide useful mapping information about historical perspectives (1970s – 1980s) of seagrass diebacks, although more recent research provides better information on seagrass habitat extents. Limited information to calculate uncertainty of the aerial estimates provided.
Edgar <i>et al.</i> (1994)	Defined differences in faunal communities between seagrass vegetated and unvegetated benthic habitats at 6 sample sites across	LOW Some indication of influence of seagrass loss on sediment and	Limited to site specific sediment cores providing some groundtruthing information about sediment characteristics and faunal communities.

STUDY	SCOPE	RELEVANCE	DATA LIMITATIONS**
	Western Port.	faunal communities.	
Stephens (1995)	An EPA study mapped seagrass distribution and abundance in Western Port based on aerial photography survey in 1994. Estimated an area of 93 km ² suggesting an increase in seagrass beds from diebacks detected in the 1980s.	MEDIUM Comprehensive seagrass mapping useful for change detection of distribution and abundance.	Provides mapping and groundtruthing of seagrass distributions mid-1990s, however limited information regarding map validation to calculate accuracy estimates.
Environmental Conservation Council (2000)	Identification and recommendations for significant environmental values in Western Port.	MEDIUM Presents 8 key areas with considered ecologically significant.	Limited summary of information from 2000 and prior.
Hancock <i>et al.</i> (2001)	Widespread sampling across entire bay to determine sediment characteristics, transportation pathways and distribution of different sediment habitats.	HIGH Important data encompassing water quality and sediment cores and grabs.	Good comprehensive georeferenced groundtruthing information of sediment characteristics and transportation.
Wallbrink <i>et al.</i> (2003)	Three year study to assess sediment sources running into Western Port and sediment redistribution within the bay.	MEDIUM Relevant information on sediment type and source.	Useful information on rates of accumulation and redistribution of sediment within Western Port over a 3yr time period. Indicates a clockwise movement of sediment where sediment in the north arm may be distributed to eastern and southern sections of Western Port.
Rogers <i>et al.</i> (2005) and Rogers <i>et al.</i> (2006)	Use of aerial photogrammetric surveys to assess mangrove encroachment of salt marsh habitat in lower Western Port. Core samples and surface elevation at four sites were	MEDIUM Relevant information for assessing change in mangrove and saltmarsh over time.	Repeated observations to assess vertical accretion changes limited to 3 – 4 years. Period of aerial photography (32 years) could provide useful mapping information to assess habitat changes for sub-tidal habits where data is optically clear for

STUDY	SCOPE	RELEVANCE	DATA LIMITATIONS**
	used to assess the role of sea-level rise and sedimentation on salt marsh decline (2005). Feldspar marker horizons were also used to measure vertical accretion (2006).		patch discrimination.
Harvey & Bird (2008)	First detailed study of rhodolith beds in south-eastern Western Port. Identified as important benthic habitat because of high associated biodiversity.	LOW Characterises ecologically important habitat rare in Western Port and presumed coastal Victoria.	Limited to sample transects of one habitat type, could provide some useful groundtruthing data for rhodolith beds and associated flora and fauna.
Shepherd <i>et al.</i> (2009)	Shepherd <i>et al.</i> (2009) charted a 66% decline in macroalgae species at Crawfish rock over a 35 year period, attributed to declining water quality and increased sediment loads.	MEDIUM – LOW Site specific information about habitat change at ecologically significant Crawfish rock.	Shepherd <i>et al.</i> 2009 provides groundtruthing information of algae assemblages at Crawfish rock from 1967 - 1971 and 2002 – 2006. This will be an ideal site to continue and ongoing comparison building on the time series data available.
Blake & Ball (2001) and Ball <i>et al.</i> (2010)	Mapping of seagrass distributions across the majority of Western Port using aerial photography groundtruthed with <i>in situ</i> underwater video observations of seagrass patch characteristics and boundaries.	HIGH Important broad coverage benthic habitat mapping data encompassing current knowledge of the majority of seagrass distributions in Western Port.	Studies will provide important mapping data. Historical aerial photography used unable to be groundtruthed (2001). Limited information on uncertainty of predictions Lack of spatial replication at fine-scale to assess seagrass health and therefore difficulties assessing changes in seagrass patch health compared to total patch area (2010).
Future Coasts (2010)	Survey of Victorian coastline to develop comprehensive high resolution digital elevation model (DEM) of shallow coastal waters using airborne LiDAR and vessel	HIGH Most current majority coverage mapping data available for Western Port (See	Airborne LiDAR had limited data coverage in Western Port due to water clarity in channels. This was supplemented with SONAR bathymetry mapping . Reduced quality of backscatter data from this survey effects the usefulness

STUDY	SCOPE	RELEVANCE	DATA LIMITATIONS**
	based multibeam SONAR surveys.	– Figure 9). Provides the best bathymetry data for the extent of western Port to date. Data has been integrated with data from Blake et al 2013 to develop broad prediction of substratum and biotic communities for the southern coastal area of Western Port.	of SONAR data for habitat mapping with approximately 50% of coverage backscatter data not recorded in survey. Data is 5 yrs old so may result in mismatch when modelling current habitat distributions.
Butler & Bird (2010)	Sampling of sediment characteristics at 10 sites to assess macroinvertebrates and sediment conditions in Western Port marine protected areas (MPAs).	LOW Most data not relevant for the current study.	Good replication of core sediment samples at study sites that can provide groundtruthing information, although many of these are outside target study area.
Edmunds <i>et al.</i> (2010)	Summarised reef and benthic biota distributions in Western Port.	MEDIUM Good summary of mapped benthic biota and geomorphology.	Data summaries limited to mapping surveys 2010 and prior.
Boon <i>et al.</i> (2011)	Full coverage vegetation mapping (mangroves and saltmarsh) of Western Port using aerial photography and extensive field based sampling to develop fine-scale habitat maps.	HIGH Most current detailed vegetation habitat mapping for mangroves and saltmarsh across Western Port.	Mapping information limited to existing aerial photography, therefore difficult to assess seasonal variation.
Barton <i>et al.</i> (2012)	Summary of natural values and habitat information for Western Port MPAs.	MEDIUM – HIGH Presents current knowledge on important ecological features and detailed mapping information	Limited to summary of existing data only and MPAs within Western Port.

STUDY	SCOPE	RELEVANCE	DATA LIMITATIONS**
		available.	
Blake et al (2013)	Comprehensive underwater video survey targeting key marine habitats in Western Port for biological and geological habitat classification.	HIGH Widespread coverage of video transects with data extracted that is precisely positioned using acoustic transponders (USBL)	Limited to groundtruthing video only with no mapping products extracted. Important widespread video information available identifying potential habitat priorities. Also sparse coverage in upper north-eastern zones.
French et al (2014)	Presents a novel method for high-resolution mapping of sub-tidal habitats by defining seagrass distributions using satellite imagery (World View 2) and LiDAR remote sensing combined with underwater video.	HIGH Most current sub-tidal habitat mapping methodology.	Study analyses limited to Western Port MPAs only (French and Yaringa MNPs, although some mapping and groundtruthing data is available beyond these extents.

3.2 Known natural values in Western Port by geographic zone

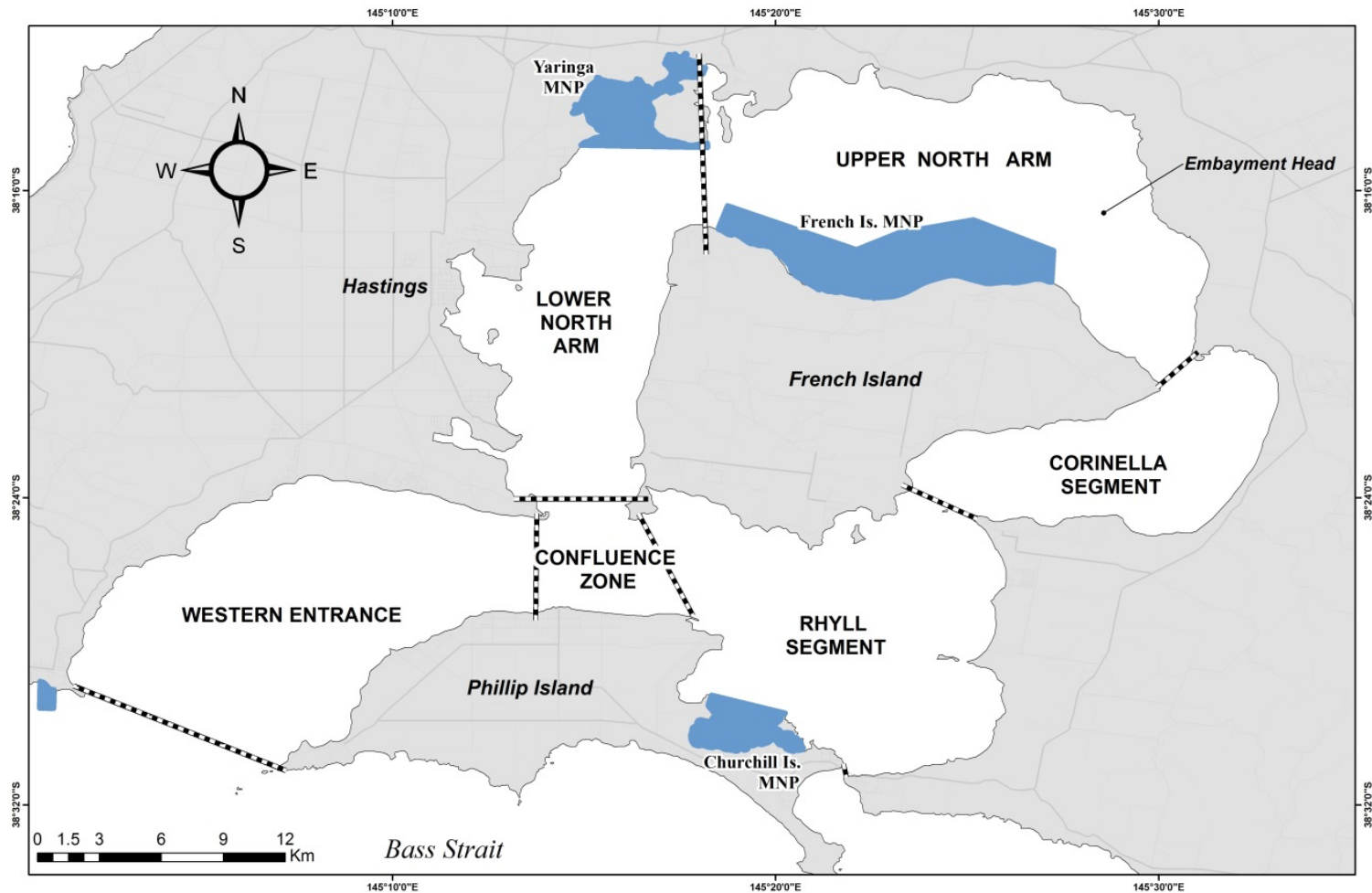


Figure 3 Western Port overview showing geographic segments as defined by Marsden *et al.* 1979. Marine protected areas are shaded blue.

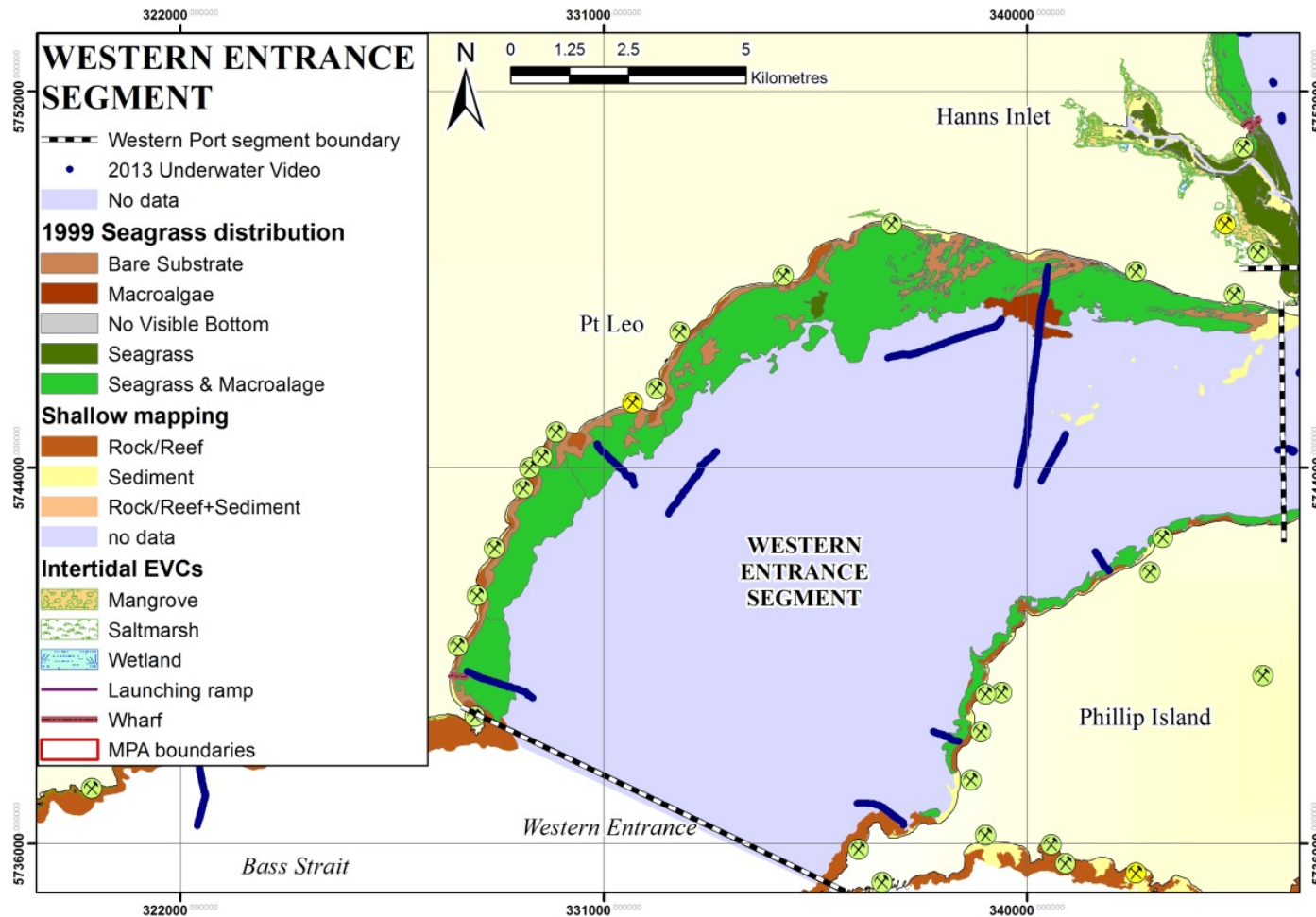


Figure 4. Western entrance geographic segment, Western Port. Habitat mapping information including seagrass (Blake *et al.* 2001), inter-tidal vegetation (Boon *et al.* 2011) and geologically significant sites; coloured markers, green = regional/local, yellow = state and purple = national/international (Rosengren 1984).

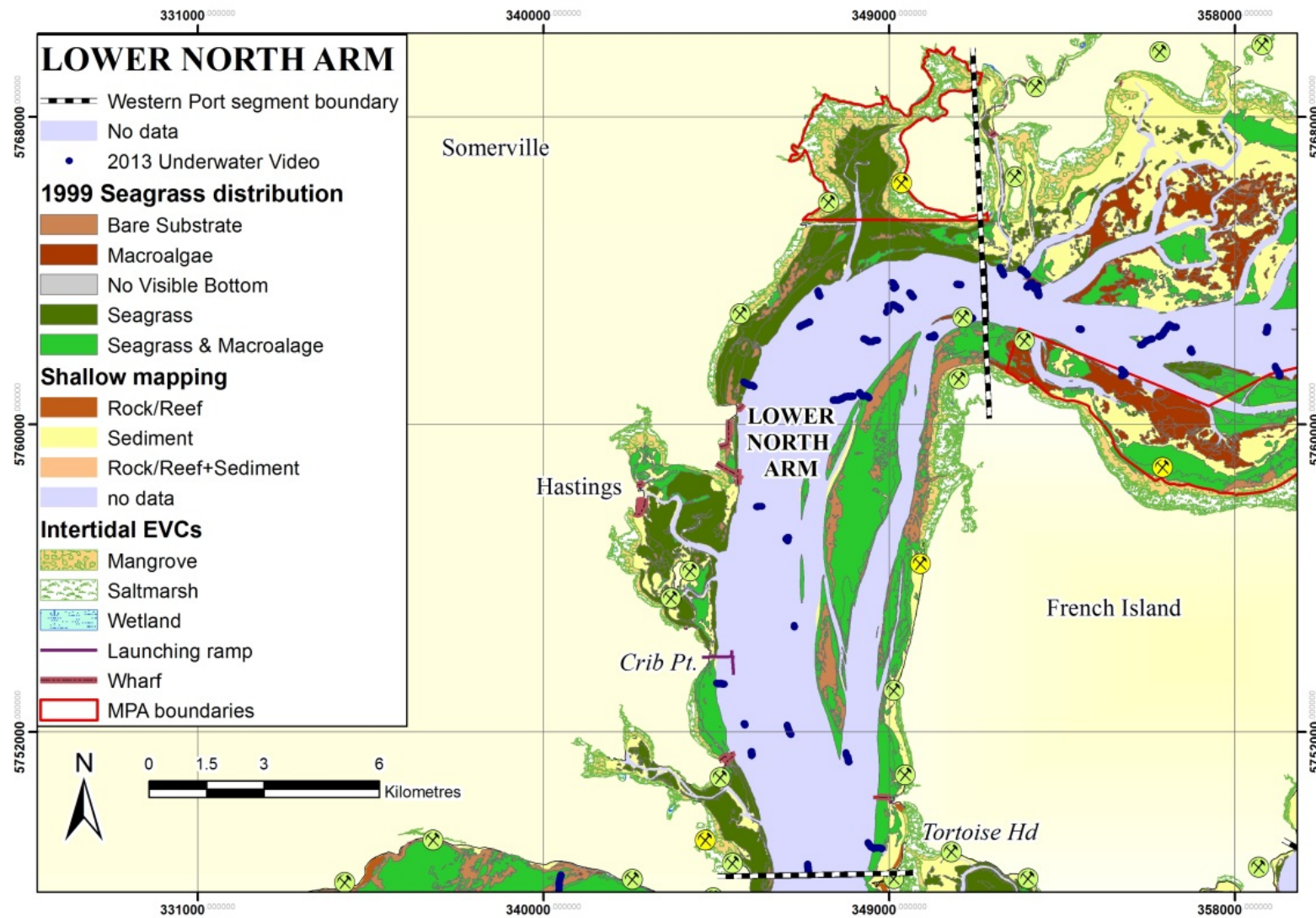


Figure 5. Lower north arm geographic segment, Western Port. Habitat mapping information including seagrass (Blake *et al.* 2001), inter-tidal vegetation (Boon *et al.* 2011) and geologically significant sites; coloured markers, green = regional/local, yellow = state and purple = national/international (Rosengren 1984).

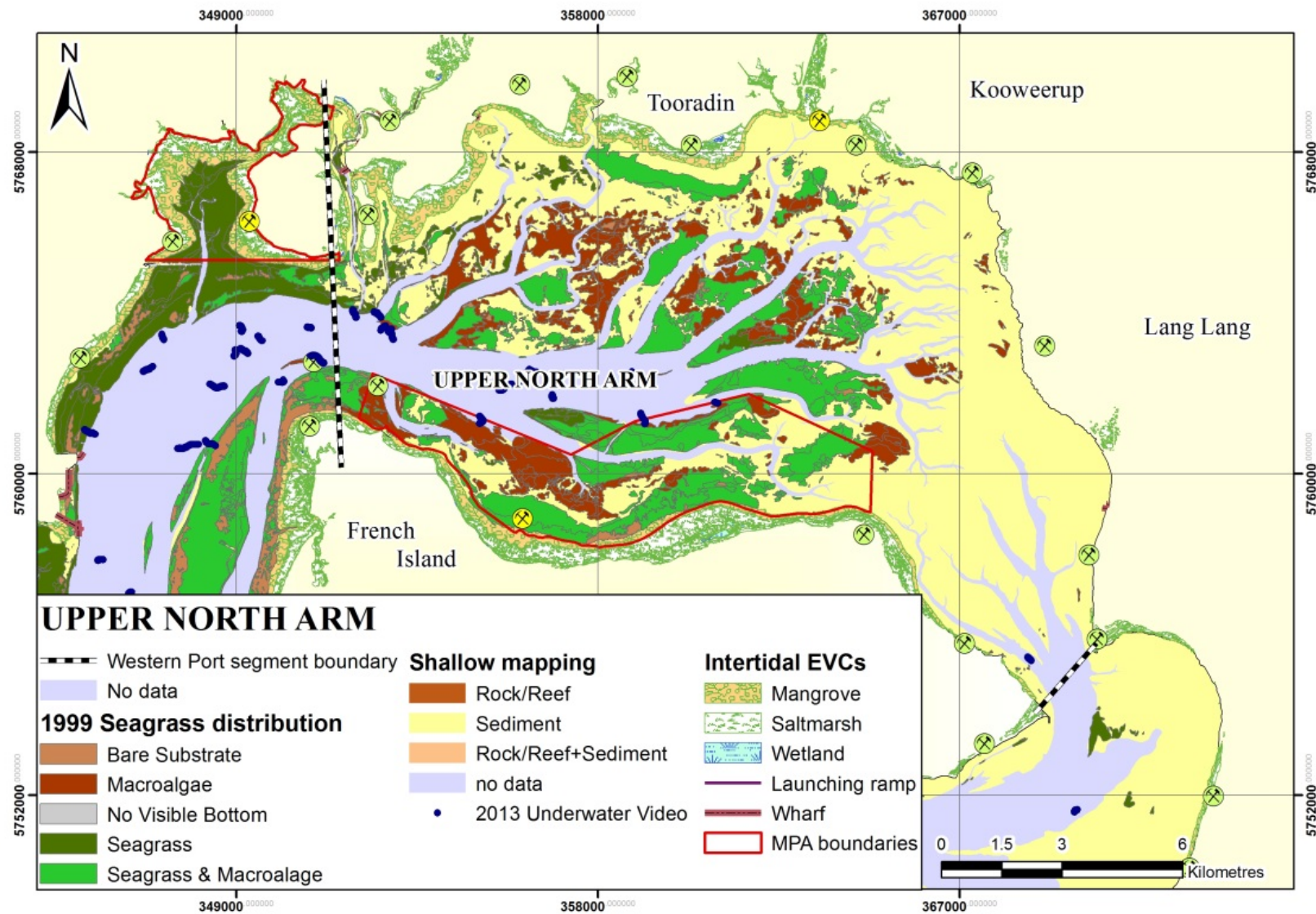


Figure 6. Upper north arm geographic segment, Western Port. Habitat mapping information including seagrass (Blake *et al.* 2001), inter-tidal vegetation (Boon *et al.* 2011) and geologically significant sites; coloured markers, green = regional/local, yellow = state and purple = national/international (Rosengren 1984).

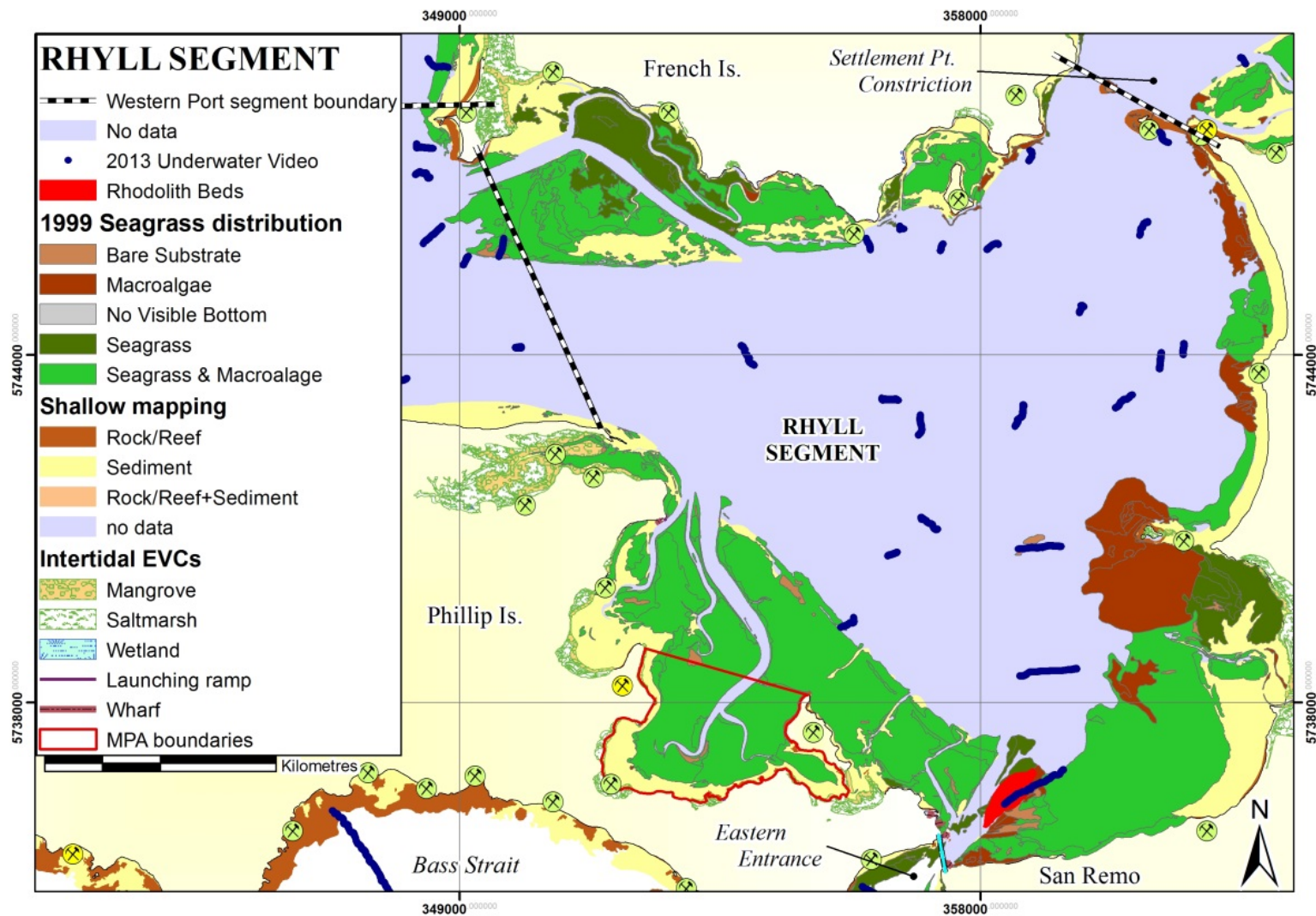


Figure 7. Rhyll geographic segment, Western Port. Habitat mapping information including seagrass (Blake *et al.* 2001), inter-tidal vegetation (Boon *et al.* 2011) and geologically significant sites; coloured markers, green = regional/local, yellow = state and purple = national/international (Rosengren 1984).

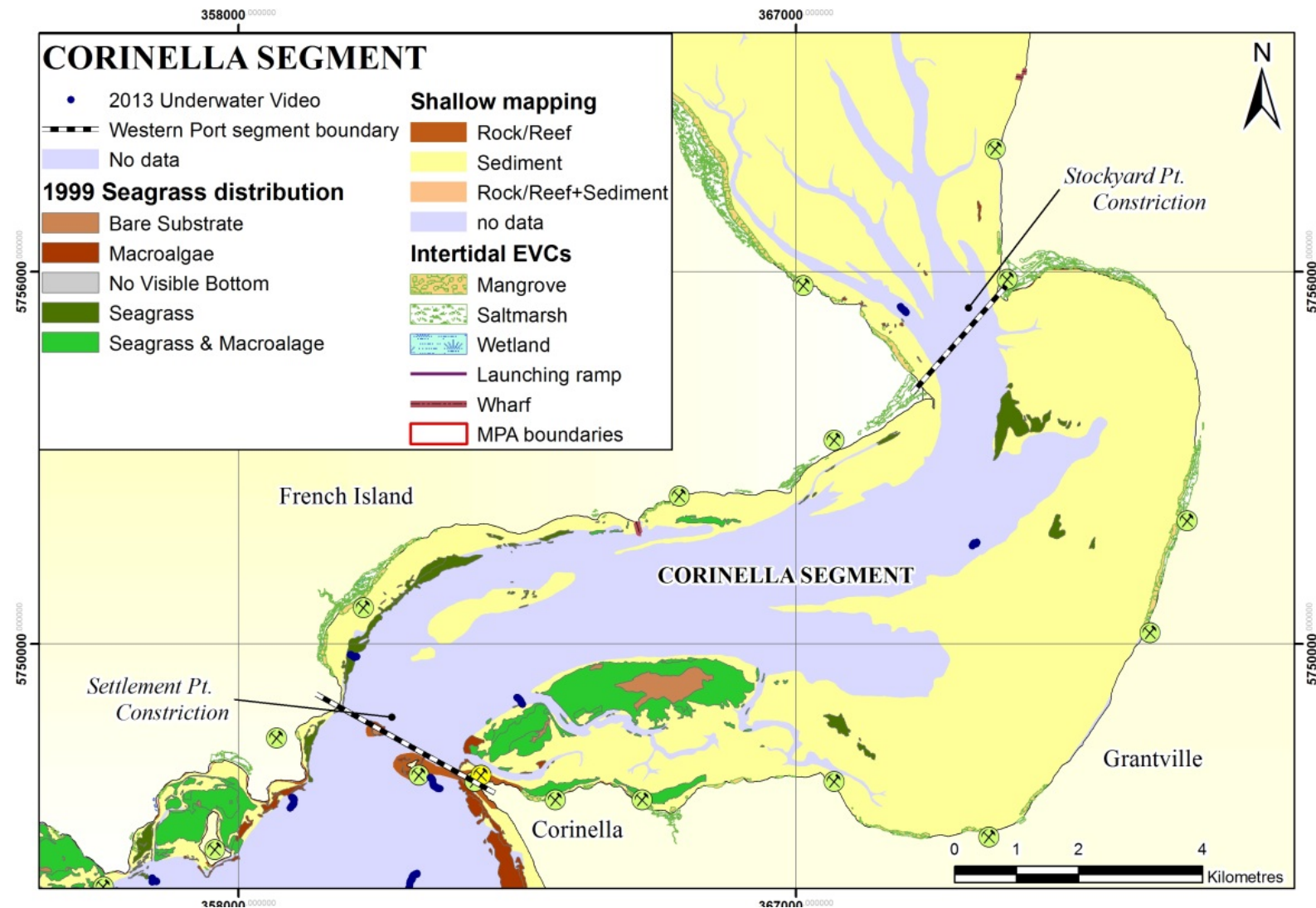


Figure 8. Corinella geographic segment, Western Port. Habitat mapping information including seagrass (Blake *et al.* 2001), inter-tidal vegetation (Boon *et al.* 2011) and geologically significant sites; coloured markers, green = regional/local, yellow = state and purple = national/international (Rosengren 1984).

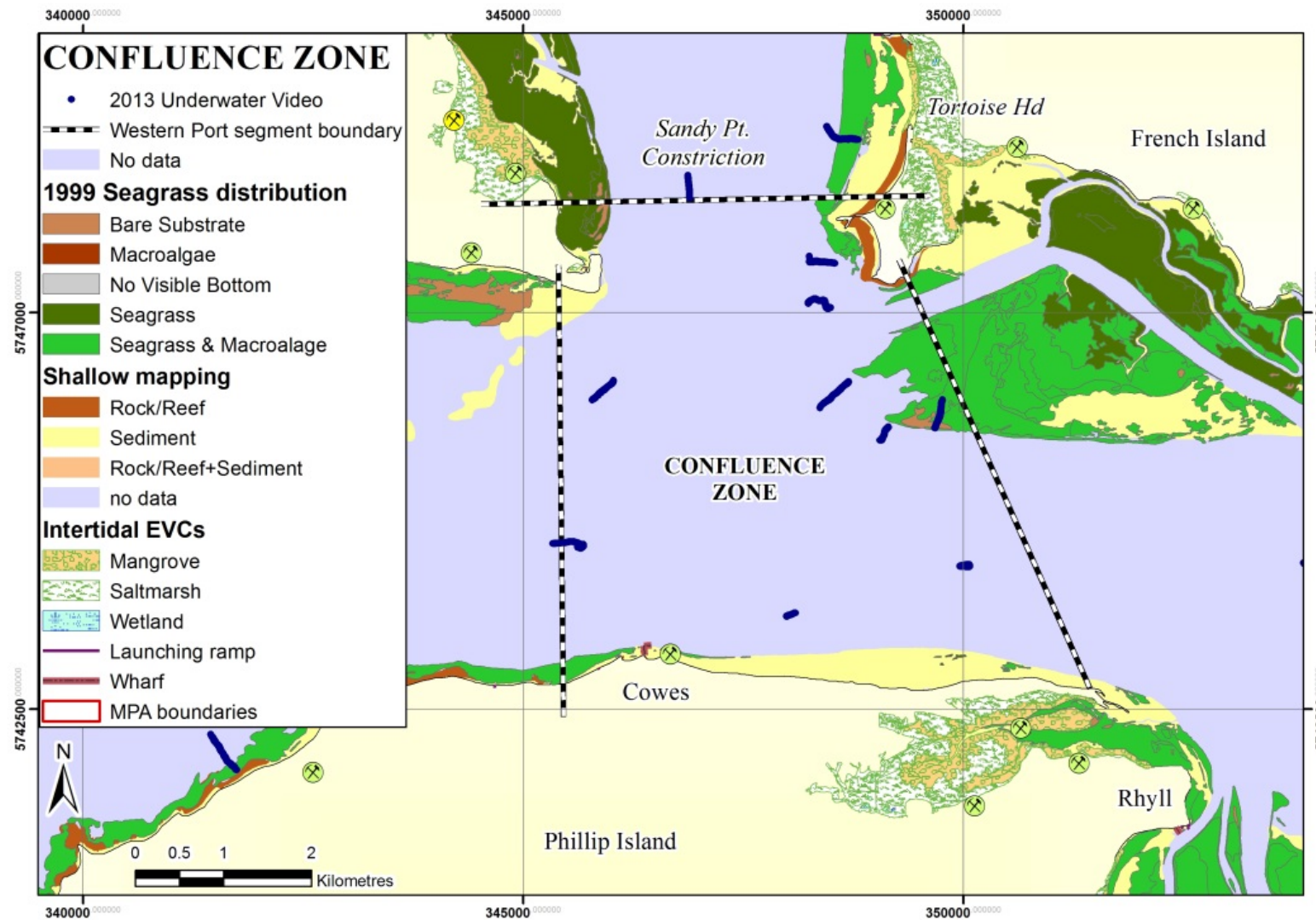


Figure 9. Confluence zone geographic segment, Western Port. Habitat mapping information including seagrass (Blake *et al.* 2001), inter-tidal vegetation (Boon *et al.* 2011) and geologically significant sites; coloured markers, green = regional/local, yellow = state and purple = national/international (Rosengren 1984).

3.3 Knowledge gaps and Conclusions

3.3.1 Summary of knowledge gaps

Table 2. Summary of key questions, existing information and knowledge requirements for benthic habitat mapping in Western Port.

KEY QUESTIONS	EXISTING INFORMATION	KNOWLEDGE REQUIREMENTS
What is currently known about Western Port benthic habitats and where are they located?	<p><u>Geophysical mapping data:</u></p> <p>In reference to mapping data that reveals an accurate digital elevation model (DEM) of the seafloor for Western Port currently there is only one dataset that has majority coverage (See Figure 10). This includes data from two sources, LiDAR and Multibeam echo sounder (MBES) (Future Coasts 2010). Pixel resolution is 5 m for LiDAR and 2.5 m for MBES. From this data we can derive accurate bathymetric information for survey areas, although textural information and resolution for fine-scale benthic habitat mapping is lacking.</p>	<p>Existing full coverage datasets provide good bathymetric maps of Western Port. However this data is limited for the purpose of fine-resolution habitat mapping due to a number of factors; 5 years old, resolution and ‘patchiness’ of LiDAR data (French <i>et al.</i> 2014) and lack of MBES backscatter data that provides important textural information for habitat classifications. This information provides signal strength for certain areas of MBES data that is useful in habitat characterisation studies.</p> <p>Contemporary full coverage high resolution bathymetry and backscatter data required for areas targeted for fine-resolution habitat mapping of biota and geomorphology.</p>
	<p><u>Intertidal vegetation mapping:</u></p> <p>Existing information of intertidal vegetation is provided by Boon <i>et al.</i> (2011). This study provides comprehensive maps of different Ecological Vegetation Classes (EVCs) in Western Port in all littoral and intertidal zones.</p>	<p>Existing data can be used to inform baseline habitat distributions of important intertidal vegetation including mangrove and saltmarsh from Boon <i>et al.</i> (2011). Recent surveys by Biosis have assessed the quality of vegetation in accordance with state biodiversity guidelines</p> <p>Future assessment or monitoring could use vegetation mapping completed by Boon <i>et al.</i> (2011) as a baseline distribution for saltmarsh and mangrove habitats.</p>
	<p><u>Subtidal habitat mapping:</u></p> <p>For subtidal areas existing habitat mapping data includes coverage of seagrass distribution (Blake & Ball 2001) and basic geophysical mapping; i.e. reef, sediment and reef/sediment mixed. Limitations of this data is its restriction to areas visible from aerial photography, hence there are large ‘no data’ areas in deeper water. Seagrass distributions are from 1999 surveys</p>	<p>Scarcity of data on benthic communities is clear not only in the priority study area but throughout the whole bay.</p> <p>Mapping of the primary area of western segments of Western Port</p> <p>Mapping of other benthic habitats, particularly deeper water including sessile invertebrate and reef communities and fringing seagrass.</p>

KEY QUESTIONS	EXISTING INFORMATION	KNOWLEDGE REQUIREMENTS
	with current seagrass extents not known.	
What is the location and extent of areas of high biodiversity and natural value significance?	<p>Study results from Shapiro (1975) determined 6 areas of ecological significance in Western Port, 3 of which have boundaries similar to Yaringa, French Is and Churchill Is Marine National Parks established in 2002.</p> <p>In addition to these existing studies have identified rare areas of high biodiversity on rocky reefs including, Crawfish Rock, Honeysuckle reef and small reef near San Remo important for opisthobranchs (Melbourne Water 2011).</p> <p>Rhodolith beds in close proximity to important elephant fish breeding habitat are located near San Remo in the Rhyll segment (See Figure 7) (Harvey & Bird 2008).</p> <p>Dense seagrass beds throughout the bay, especially in the Corinella, Rhyll segments and in the north arm in Yaringa and French island MNPs (Blake & Ball 2001; French et al 2014) represent one of Western Ports most important natural values.</p> <p>Other important vegetation habitat includes extensive saltmarsh and mangrove vegetation along the coast in the north arm and around the northern coast of French Island (Boon <i>et al.</i> 2011)</p>	<p>Comprehensive mapping of intertidal saltmarsh and mangrove systems was published by Boon et al 2011 and is current</p> <p>Mapping of the extent and composition of intertidal and subtidal seagrass is required as the most recent mapping was completed in 1998 and does not represent current distribution.</p> <p>Mapping of soft sediment invertebrate (epi and infauna) community distribution across Western Port which includes a wide range of shallow and deep water subtidal habitats harbouring filter feeding invertebrates that exist in the bay.</p>
How do we monitor ongoing change and effects for seafloor habitats?	<p>To assess future impacts it is highly important to define current baseline information. However, effective baseline data from existing sources is limited for most habitats in Western Port. The most comprehensive information is for seagrasses (Blake & Ball 2001) and mangrove and saltmarsh vegetation (Boon <i>et al.</i> 2011).</p> <p>High resolution baseline geophysical datasets are available from the Future</p>	<p>Identify prioritise and map regional reference habitat sites in Western Port. Key sources to support and guide prioritisation are Blake & Ball (2001) for seagrass and Blake <i>et al.</i> (2013) for all other benthic habitats. Anecdotal evidence derived from existing literature reviews such as Melbourne Water (2011), Edmunds <i>et al.</i> (2010) and KBR (2010) is also important for defining ecologically important sites.</p>

KEY QUESTIONS	EXISTING INFORMATION	KNOWLEDGE REQUIREMENTS
	<p>Coasts (2010) project with good coverage, albeit 5yrs old (Figure 10). However such datasets are limited in their application for fine-resolution habitat mapping due to temporal discrepancies and collection procedures not optimised for habitat mapping purposes (gain change in LIDAR intensity data and missing MBES backscatter data).</p> <p>Blake <i>et al.</i> (2013) provides the most comprehensive video data of benthic communities which is useful for prioritisation of sampling sites.</p>	
What information is available for inter-annual and seasonal variation in key habitats and approaches for assessment?	<p>Few existing studies have incorporated temporal components for assessment of benthic communities in Western Port.</p> <p>Inter-annual datasets of mangrove and seagrass aerial photography have allowed assessment of these vegetation types over time (Bird 1986, Bulthuis 1984). For example Bird (1986) showed there has been some recovery of mangrove stands overtime since the 1930s along the northern coast. It should be noted that considering the variety of techniques and approaches applied and the lack of validation approaches it is difficult to quantify uncertainty in data presented in most circumstances.</p> <p>The most substantial temporal variation for Western Port is expected in sedimentation pathways, phytoplankton assemblages and sediment faunal communities (Melbourne Water 2011).</p>	<p>Integrate mapping data capture with other specialist studies to support defining natural variability in the system.</p> <p>Review historical temporal data sets to define variability in ecological values and review the accuracy of temporal data to define the limits of acceptable change.</p>

KEY QUESTIONS	EXISTING INFORMATION	KNOWLEDGE REQUIREMENTS
What information is available to define cover of habitats at the time of its listing (1982) as a Ramsar site?	<p>The development of the ecological character description in 2010 placed a retrospective requirement for the baseline information expressed as limits of acceptable change (KBR 2010).</p> <p>Aerial photography of seagrass extent is available during the late 1970s and 1980s where approximately 170 km² was lost. Approximately 34 km² of seagrass recovered between 1983-84 and 1994 (Stephens 1995). Accuracy of data is questionable as limited groundtruthing was undertaken at the time.</p> <p>No data is available for mangrove and saltmarsh distribution between 1983 and 1996. Estimates by the Victorian Institute of Marine Science (EPA 1996) indicated 31,000 Ha of saltmarsh and mangrove but estimates did not account for the Ramsar boundary.</p> <p>Limits of acceptable change for soft sediment (intertidal and subtidal) marine invertebrates have not been established due to a limited understanding of diversity and abundance within the site (KBR 2010).</p>	<p>Detailed review of data sources to determine distribution of seagrass, saltmarsh, mangrove and invertebrate communities to assess distribution and review against contemporary data for marine habitat mapping and natural variability identified as part of other specialist studies.</p>

3.3.2 Practicality of Habitat Mapping in Western Port

Benthic habitat mapping in Western Port is limited by difficult survey conditions (e.g. turbid, shallow water), hence there is a lack of information characterising benthic communities and geomorphology for many areas. Currently the most comprehensive mapping datasets is a combination of LiDAR for shallow intertidal areas and MBES in deeper channel habitat (Figure 10). Although this dataset provides high resolution bathymetry information over a large coverage area, textural information important for fine-resolution mapping of biotic communities is lacking. Furthermore the resolution of LiDAR data means its application for biological habitat mapping is limited. The LiDAR data can be useful for broad classification of benthic habitats but it has a somewhat reduced accuracy for subtidal vegetation mapping (French *et al.* 2014) in comparison to high resolution MBES. The LiDAR/MBES data are 5 years old therefore we are uncertain whether they represent current habitat conditions in Western Port.

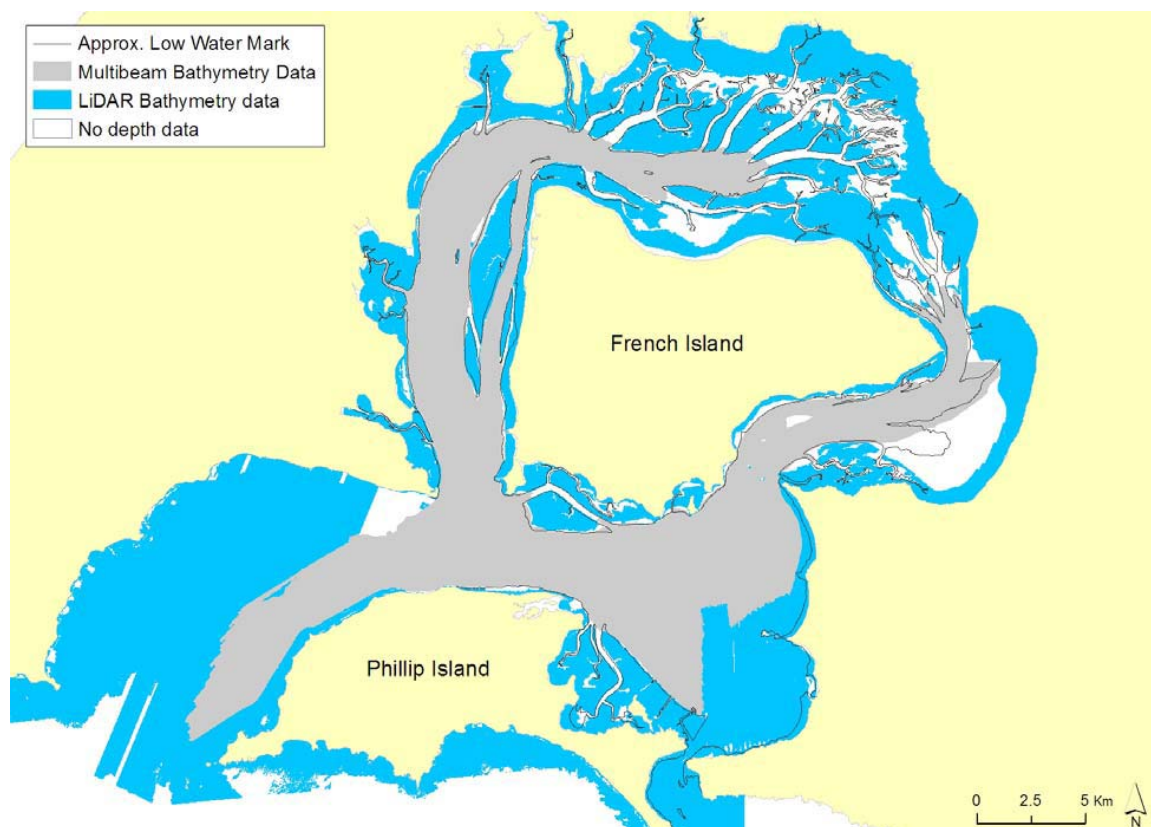


Figure 10. Western Port showing survey extents of most recent mapping as part of the DSE Future Coasts program. LiDAR 2010 survey (blue) and Multibeam SONAR (MBES) 2010 survey (grey). Source - Blake *et al.* 2013. Note whilst bathymetry data is provided there are issues in data quality and coverage for intensity (LiDAR) and backscatter (MBES) data products within Western Port which are important for habitat mapping.

Aerial photography and satellite imagery have proved the most effective techniques for shallow water mapping of Western Port. There are comprehensive datasets available for intertidal saltmarsh and mangrove vegetation (Boon *et al.* 2011) and shallow water seagrass (Blake & Ball 2001). Seagrass mapping is detailed and effectively groundtruthed with field observations however it is now 15 years old and may not accurately reflect current distributions. Furthermore seagrass mapping is restricted to areas where the seafloor is visible through aerial photography, hence the

majority of channel areas and deeper water is not mapped for seagrass or other benthic biota. These habitats are currently considered 'no data' areas with very little classification of benthic assemblages or geophysical characteristics even though existing video observations have shown important ecological communities (Blake *et al.* 2013) and likely underestimating the current extent of seagrass.

Current groundtruthing video observations within deeper water areas provides an important indication of the type and diversity of benthic assemblages where there is otherwise no other georeferenced information (Blake *et al.* 2013). Such information that is point located and classified for density of different benthic biota is extremely useful for prioritising reference sites and ecologically significant habitat patches for future monitoring.

3.3.3 Review of available technology for habitat mapping

The general approach for benthic habitat mapping requires full coverage of the study area of interest to provide information of the environmental/ geophysical characteristics. This is often then combined with some information to ground truth the geophysical data to identify habitats to infer relationships and makes predictions of habitat extents across the full coverage areas achieved. Western Port due to its complex hydrodynamics and turbidity makes some traditional approaches to habitat mapping challenging. This has resulted in a bias of coverage in ecologically important habitats in shallow water environments (Blake and Ball 2001; Boon 2011).

If full coverage habitat data for Western Port is required it is likely that a multiple approaches will be required. Here we summarise options for geophysical (to characterise the environment) and biological data collections and their associated limitations.

Geophysical Data

The options for geophysical data collection need to take into consideration the coverage proposed to be achieved in Western Port. The Future Coasts Program showed the potential for collecting baywide coverage of shallow water habitats using bathymetric LIDAR in Western Port (Fugro LADs system). Unfortunately recent trials with a different bathymetric LIDAR system were not as successful and were deemed not feasible for baywide shallow water coverage. The main limitation with bathymetric LIDAR systems is their penetration capabilities, generally around 2.5 time secchi depth, problematic in areas such as Western Port which are notably highly turbid particularly in the North eastern section of the embayment. Turbidity is equally problematic for other spectral acquisition systems such as aerial or satellite imagery. Satellite imagery acquisition was an issue for French *et al.* 2014 who used an archived Worldview multispectral image due to issues obtaining a suitable cloud free image close to the time of video observation data collection. Plane based platforms may negate issues with satellite systems regarding cloud cover and provide more alternatives for data acquisition in optimal tidal conditions. Aerial photography has been applied to map mangroves and saltmarsh (Boon *et al.*, 2011) and seagrass habitat (Blake and Ball 2001). In the absence of a suitable bathymetric LIDAR system (which will provide the advantage of bathymetry and intensity data) plane based hyperspectral/ multispectral sensors alone may provide a cost effective alternative to obtaining baywide coverage for shallow waters for the purpose of habitat characterisation. All the options above are limited to shallow (<5m at best) water and acoustic

approaches provide the best option for geophysical data collection for the deeper regions of Western Port. Multibeam echo sounder sounders (MBES) provide the best approach for achieving seafloor coverage in deeper waters and provide high resolution geo-physical datasets that can be used to explore patterns of both broad and fine scale ecosystem dynamics in benthic habitats. The advantage of using MBES over other acoustic sensors such as single beam echo sounders or side-scan sonars is that complete seafloor coverage can be achieved, and that bathymetry and backscatter (intensity of acoustic returns) are co-registered.

Groundtruth data

Irrespective of the geophysical data collection chosen the collection of groundtruth data of biological habitats is imperative for model development and validation. Due to their non-destructive nature video techniques are becoming a standard approach for the collection of biological information. The main challenges if using such approaches in Western Port is turbidity that can impact video quality and the capability to distinguish between habitat types. Ground-truth acquisition can be maximised by working with optimal tidal conditions within the embayment, however sections in the north east component are likely to be problematic. In such cases benthic grabs may provide an alternative to providing an indication of habitat present. In all cases care should be taken to enable the groundtruth data to be appropriately georeferenced. Differential GPS may be adequate for drop camera and benthic grabs. However for towed platforms, Remotely Operated or Autonomous Vehicles underwater acoustic positioning using ultra short base line systems (USBL) or equivalent will be essential. Ideally geophysical and biological acquisitions should be timed in such a way to minimise temporal discrepancy between the data sets.

4. Study Plan Proposal

4.1 Baseline Habitat Survey

4.1.1 Survey area and summary

The area of interest (AOI) for a marine habitat mapping baseline survey plus regional reference sites is defined in Figure 11. Surveys will be undertaken using the following approaches

- Hydroacoustic survey using multibeam echo sounder
- Towed video survey
- Analysis of geophysical data (MBES bathymetry, MBES backscatter) will be processed to derive habitat models of the area

The methodological approach will involve five major components: **(1)** MBES data collection, **(2)** Geophysical data processing, **(3)** ground-truth prioritization, **(4)** video data collection, and **(5)** habitat classification.

A hydroacoustic survey of the waters deeper than 5 m within the AOI will be conducted using a Kongsberg Maritime EM2040C Multibeam Echo sounder (MBES) within the Lower North Arm, Confluence zone and Western Entrance. Additional reference sites outside this AOI will be targeted to gain baseline data on important representative habitats of ecological significance across Western Port. This system captures ultra-high-density bathymetry and backscatter data. Backscatter data is the strength of the acoustic signal return, which is dependent on the “roughness” and “hardness” of the seafloor and is thus useful for inferring seabed or habitat types. The MBES survey will be conducted so as to acquire full coverage at a sub-metre resolution. Since the swathe width (cross track coverage) of MBES systems is dependent on water depth, we have used existing bathymetry data to estimate the total duration of the MBES survey effort needed. Using the total surface of the AOI and its average depth, it can be estimated at approximately 32 days (25 days for AOI and 7 days for regional reference sites) (Table 3).

A video survey will be undertaken using a towed video system precisely positioned through the use of an Ultra Short Base Line (USBL) system. A drop video approach will be undertaken where towed surveys are not feasible due to navigation hazards. These two techniques will be used to identify the benthic communities within the AOI. The video survey effort is to comprise 12 days to ground-truth the area covered by the MBES survey in the Lower North Arm only (on the basis that this is the area where dredging and Port construction would occur and be most affected) and 4 days to ground-truth additional regional reference sites (Table 4).

The geophysical data (MBES bathymetry, MBES backscatter) will be processed into geophysical derivatives (i.e. slope, surface ruggedness, etc.), which will provide the input for the development of models designed to characterise marine habitats within the AOI. These models follow a methodology designed and refined as part of Deakin University studies over the past decade (Ierodiaconou *et al.*, 2011), which consist in applying automated classification techniques to integrating geophysical data with observation data from video ground-truthing (Figure 13).

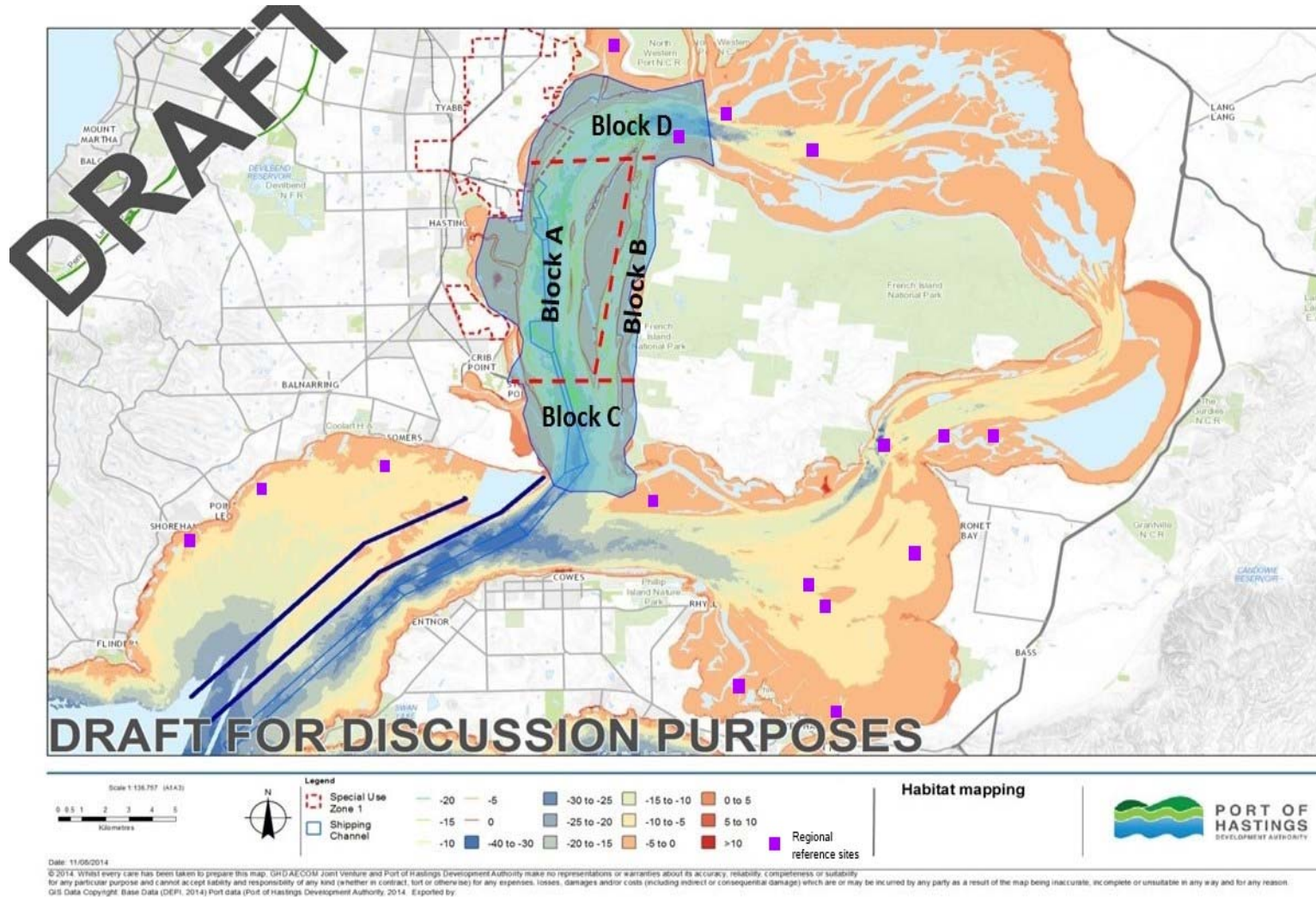


Figure 11. Proposed survey areas for habitat mapping. Blue polygon indicates multibeam sonar coverage of areas deeper than 10 m. Thick blue lines indicate area of supplementary multibeam survey of deep channel habitat. Suggested locations for regional habitat reference sites are shown in purple squares. Not to scale and for illustrative purposes only.

4.1.2 Multibeam SONAR data collection

All survey equipment is to be fitted to Deakin University's customised 9.2 m habitat survey vessel *Yolla*. Proposed planning and time estimates for the MBES survey are included in Table 3. Weather windows will be targeted to enable optimal survey conditions for data collection. We propose to have the survey vessel on standby onsite at Hastings if suitable secure shedding/mooring facilities can be located. This will minimise the mobilisation time by removing the need to remobilise, re-fit equipment and re-perform calibration tests between each survey leg.

MBES data will be acquired using the latest-generation shallow-waters EM2040C by Kongsberg Maritime. The EM2040C transmits short acoustic pulses (pings) at an operating frequency of 300 kHz within a narrow across-track swath (1.3° alongships), and receives the echo resulting from the interaction of the pulse with the seafloor within 256 narrow beams (1.3° athwartships) electronically steered in the across-track plane between -65° and + 65°. This geometry results in the system forming 256 narrow beams (1.3x1.3°) in a wide across-track swath (130°) allowing coverage of approximately 4.3 times the water depth (assuming flat seafloor). The transmit and receive beams are electronically steered to compensate for the vessel roll and pitch movements in real time and keep the acoustic swath stable at the vertical under the vessel. New Kongsberg Maritime firmware allows the EM2040C to acquire multiple soundings for the outer-swath beams and to steer electronically the individual beams so as to produce 400 equidistant soundings per ping. The EM2040C has a variable ping rate (up to 50Hz) and pulse length (down to 0.025ms) that automatically adjust to water depth to achieve the highest ping density and highest resolution possible given the depth conditions.

The variation of sound velocity with depth, which affects underwater acoustics measurements, will be measured by two sound velocity sensors: a Monitor SVP by Valeport Ltd, which will be deployed at least once daily to measure sound velocity throughout the water column, and a Mini SVP by Valeport Ltd, which is setup next to the EM2040C sonar head to continuously measure sound speed at that depth during survey operation. Kongsberg Maritime software SIS seamlessly combines these two sound velocity data inputs to apply real-time sound speed corrections to the acoustic measurements.

The EM2040C on *Yolla* is integrated with an Applanix POS MV WaveMaster that provides accurate measurements of the MBES position (latitude, longitude, altitude) and motion (heave, pitch, roll and yaw). The POS MV is setup on *Yolla* so as to receive real-time RTK corrections from the state-wide network of Global Navigation Satellite System (GNSS) base stations "Vicmap Position – GPSnet". Real-time navigation, data-logging, quality control and display will be undertaken on-board using software SIS by Kongsberg Maritime and POSView by Applanix.

The EM2040C has the capability to log acoustic data from the water column between the survey vessel and the ensonified seafloor. Such water-column data can be logged in specific regions of interest, to be prioritised following discussion with GHD staff and marine experts, if desired.

The MBES survey will be conducted so as to acquire data at a resolution that conform to the change-detection assessment approach pioneered by Deakin University. Such resolution allows for the

potential detection of fine-scale changes in habitat distribution between data time-series, should subsequent surveys occur.

Table 3. Multibeam duration estimate based on average depth and area estimates in survey blocks

Site	AOI MBES Survey					Regional Reference sites	TOTAL
	Block A	Block B	Block C	Block D	Channel section		
Mean depth (m)	15	10	15	12	18	TBA	-
Line space (m)	45	30	35	30	60	TBA	-
Width (m)	3000	1000	4000	6000	21000	TBA	-
Length	10000	10000	5500	4000	1000	TBA	-
No. lines	67	33	89	150	350	TBA	689
Total length (km)	667	333	489	600	350	TBA	2439
Survey time (hrs)	67	33	49	60	35	67	311
Survey time (days)	7	3	5	6	4	7	32

4.1.3 Geophysical data processing

The navigation data collected by the POS MV, the bathymetry and the backscatter data collected by the MBES system will be processed in four stages.

First, the navigation data will be post-processed using Applanix Software POSPac MMS to combine the GNSS and inertial data acquired in real-time by the POS MV with post-processed RTK corrections from GPSnet to produce more accurate position and orientation of the sonar head during the survey. The improvement of the vertical accuracy ($\sim \pm 2$ cm) of the sonar position during the survey implies that soundings can be corrected to the desired vertical datum without the need to collect tidal information from modelled or existing tide gauges and without the need to measure the vessel squat or list during survey operations. The navigation data are processed in POSPac MMS as a Smoothed Best Estimator of Trajectory (SBET), which can then be exported to aid in bathymetry data processing.

Then, bathymetry data will be processed with CARIS software HIPS&SIPS v8.2. Processing includes overwriting the real-time navigation with the SBET solution, cleaning the soundings manually and through the use of automatic filters, and gridding using the CUBE algorithm. The bathymetry grid is then exported to IVS software Fledermaus for interpolation and visualisation.

Next, backscatter data will be processed with IVS software Fledermaus Geocoder Toolbox (FMGT). The processing consists in creating a “backscatter mosaic”, that is, an acoustic picture of the seafloor in which tonal and textural variations are representative of changes in seafloor-type. The density of backscatter samples being higher than that of the bathymetry soundings, the backscatter mosaic can usually be created at a better resolution than the corresponding bathymetry grid. The backscatter

mosaic can be created at a resolution between 0.2 and 1m depending on the data overlap and survey speed.

Last, MBES bathymetry data will be integrated in ESRI software ArcGIS 10.2. Secondary products will be derived from the combined MBES-LiDAR bathymetry dataset and the backscatter mosaic using a range of techniques and applications in ENVI 4.8 and ArcGIS 10.2. Products derived from the combined bathymetry dataset may include slope, aspect, benthic position index, maximum curvature, rugosity and complexity. Products derived from the backscatter mosaic may include textures features calculated from grey-level co-occurrence matrices, hue-saturation-intensity transformations and object-based segmentation images based on backscatter intensity similarity. Similar derivative products will be developed from the bathymetric LiDAR bathymetry and intensity data delivered by the proposed consultants.

4.1.4 Groundtruth data prioritisation

Unsupervised clustering of the datasets derived from MBES data will be performed to prioritise where ground-truthing will be undertaken and enable the assessment of the representativeness of the site. A k-means clustering approach will be used to segment the AOI into areas with similar geophysical characteristics. This segmentation technique will include an object-based image analysis approach for feature extraction, pattern recognition using fuzzy logic membership and customised segmentation algorithms. Visual examination of the backscatter mosaic will also provide a preliminary model of seafloor-type distributions across the AOI. The automatic segmentation, the manual seafloor-type identification and existing biological knowledge will be used to develop a ground-truthing survey design that will enable the whole range of geophysical conditions to be targeted.

4.1.5 Video data collection

The video surveys will provide the biological community identification “groundtruth” data that is to be used by the models to develop the relationships between marine biota and the geo-physical datasets derived from MBES. The video survey techniques developed at Deakin University allow for rapid survey over large areas beyond the range of conventional methods such as diver surveys. Deakin University’s 9.2m research vessel *Yolla* will provide the platform for the video survey operations.

Camera systems will be acoustically positioned using a TrackLink USBL system by LinkQuest Inc. The Applanix POS MV WaveMaster setup on *Yolla* combined with the real-time input for RTK corrections from the Vicmap Position – GPSnet network will provide precise vessel position and motion to accurately position the video camera systems relative to the vessel. This hardware integration enables the precise location of video information with a spatial accuracy of <2m at depths less than 40 m. The video data will be classified using the Victorian Towed Video Classification Program developed by CI Ierodiaconou. The access program was designed to allow the direct import of camera positional information, classification of video data into predefined hierarchal levels for substrata and biological communities using pull down menus, and direct export to geo-statistical packages for further spatial analysis.

Table 4. Groundtruth underwater video survey duration estimate.

Site	AOI MBES Survey	Regional reference sites	TOTAL
Video capture (days)	12	4	16
Data processing and extraction (days)	36	12	48

Two video survey methods will be deployed (Survey duration, Table 4):

1. Towed camera system/remotely operated vehicle (Figure 12). These systems will be used to collect continuous video transect information over areas of MBES coverage. This continuous information allows for the classification of benthic biological communities (e.g. dominant algae and invertebrates) and the identification of habitat transition zones.
2. Drop video. A geo-located drop video camera will be deployed in areas where shallow waters constitute a navigation hazard and for areas where towing a camera system or using a remotely operated vehicle can lead to damage to the underwater fauna and flora or to the camera equipment.

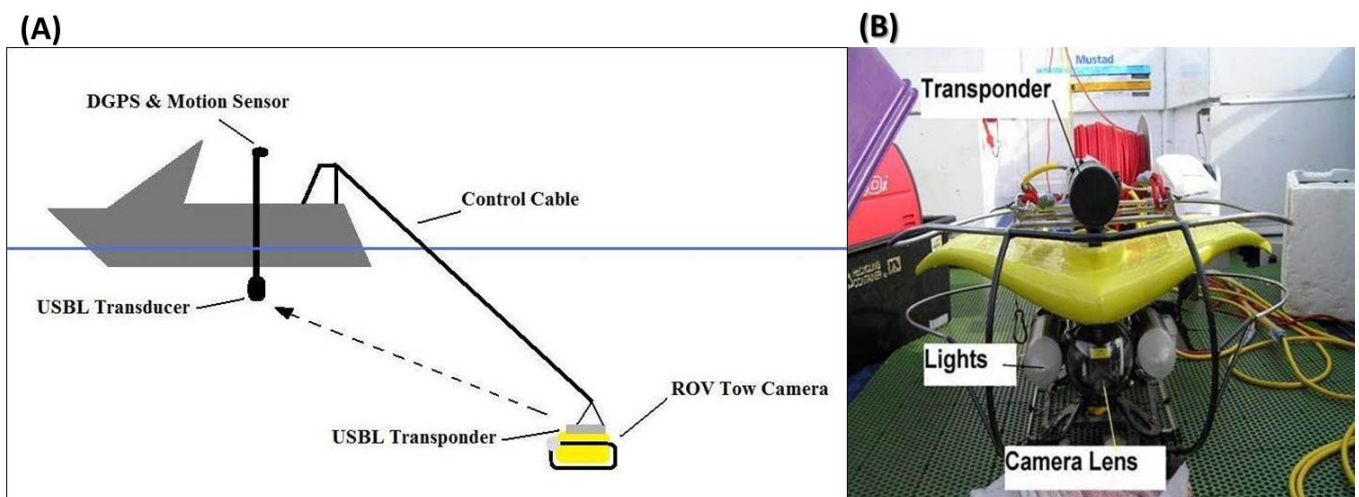


Figure 12 Underwater ROV tow video system used for collecting georeferenced video footage of benthic habitats. (A) Diagram of video system positioning with research vessel, (B) VideoRay ROV.

4.1.5 Habitat classification

A supervised image classification approach will be applied to create biotic and substrate maps using the geophysical derivative data products available and the groundtruth video information (See Figure 13 for processing schematic example for multibeam data). One of the techniques used will be a decision tree classification algorithm where a series of binary decisions are applied where

individual pixels are placed into one of two categories for each node of the decision tree with no constraint on the number of nodes used (ENVI 4.2 RSI). Seventy percent of the video information will be used to develop representative signatures from the derivative product layers for each of the biotic and substrata categories defined. The remaining 30% of the information will then used to independently assess the accuracy of the final classification results. The classification tree is dependent on the discrimination of distinct environmental signatures for each biotic and substrate class which will be identified through in situ visual analysis (video ground-truth data). It is envisaged as physical data products explaining the hydrodynamics become available they can be included into the classification process and techniques applied to infer the geophysical variables most influencing the biotic patterns observed.

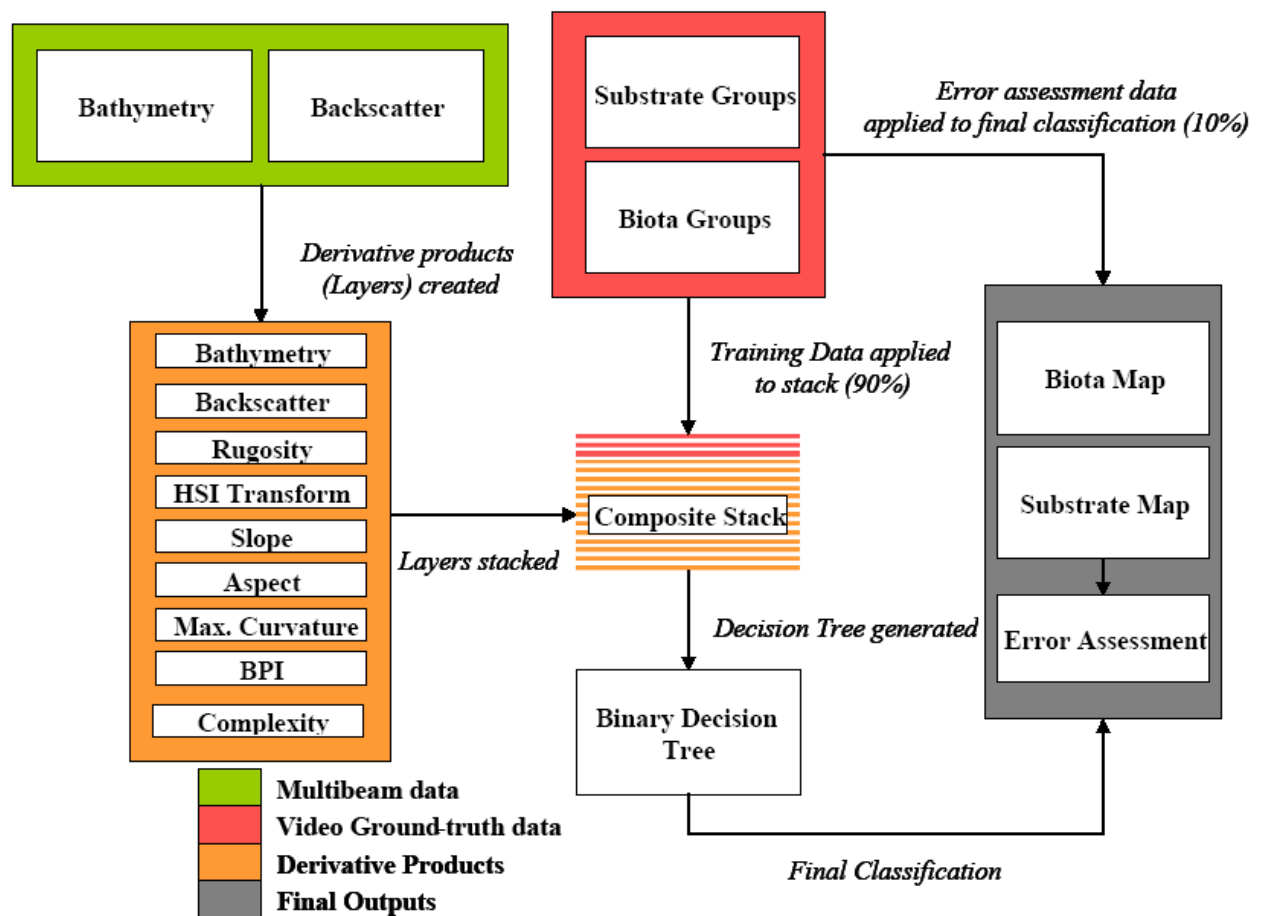


Figure 13. Schematic showing processing steps for the production of dominant biota and substrata maps using a decision tree classification technique using Multibeam (Ierodiaconou *et al.* 2011).

Mapping output and deliverables

1. Detailed baseline benthic habitat maps for Western Port AOI survey area
2. Identification of suitable subtidal habitat monitoring locations

3. Detailed classification of video data collection
4. Baseline habitat surveys and habitat maps of regional reference sites in Western Port
5. GIS data (e.g. classification maps, shapefiles, metadata) containing field work results and photographs.

4.2 Monitoring Environmental Response

4.2.1 Regional reference sites

Regional reference sites have been proposed as part of the baseline habitat survey to enable the comprehensive representation of different habitats throughout Western Port. These sites are suggested for baseline information (i.e. regional control sites) to be used as part of a Before After Control Impact (BACI) monitoring design. To adequately measure impacts to benthic habitats in Western Port we propose small-scale, representative sample sites that can be used for repetitive sampling programs of impact assessment. Sampling of regional reference sites will encompass small MBES patch surveys (7 days – Table 3) and tow video data (4 days – Table 4) to be collected at each site. Site prioritisation has been determined using existing information of benthic habitats in Western Port to target all dominant subtidal habitats and areas of high ecological significance (Table 5, Figure 14). In addition to these regional reference sites, impact and control sites will be defined within the overall MBES survey in the lower north arm. These sites will not require any additional sampling for the baseline habitat survey but are important for assessment as part of a BACI monitoring design.

Table 5. Proposed location of regional reference sites, including habitat and biota type. Site numbers cross-referenced with Western Port sampling map – See Figure 14.

Important reference sites	Western Port segment	Substratum	Relevance and representative habitat
1.Crawfish rock	Lower north arm	Reef	High profile reef high biodiversity of sessile invertebrates/macroalgae
2.Eagle rock	Lower north arm	Reef	High profile reef high biodiversity of sessile invertebrates/macroalgae (Blake et al 2013)
3.Honeysuckle reef	Western entrance	Reef	High diversity of sessile invertebrates/macroalgae (Melbourne Water 2011)
4.Western entrance reef	Western entrance	Reef	Diversity of macroalgae , especially phaeophytes (Blake et al 2013)
5.San Remo shallow reefs	Rhyll segment	Reef	High diversity of sessile invertebrates/macroalgae , important for opisthobranchs (Melbourne Water 2011)
6.Rhyll high profile reef	Rhyll segment	Reef	High profile reef with sessile invertebrates/macroalgae (Blake 2013)

7. Corinella reef holes	Corinella segment	Reef	Unique geomorphology, sessile invertebrates
8. Corinella seagrass	Corinella segment	Sediment	Dense seagrass beds (Blake & Ball 2001)
9. Corinella channel	Corinella segment	Sediment	Sediment slopes, fauna burrows and sessile invertebrates
10. Upper north arm sea pens	Upper north arm	Sediment	Sessile invertebrates on sediment; sea pens, bryozoans, sponges, ascidians (Blake et al 2013)
11. North arm channel	Upper north arm	Sediment	Sediment slopes, fauna burrows and sessile invertebrates (Blake et al 2013)
12. Yaringa MNP seagrass	Lower north arm	Sediment	Dense seagrass beds
13. Western entrance seagrass	Western entrance	Sediment	Dense seagrass beds
14. Churchill Is. seagrass beds	Rhyll segment	Sediment	Seagrass/macroalgae
15. San Remo seagrass	Rhyll segment	Sediment	High seagrass diversity near San Remo eastern channel entrance (Blake et al 2013)
16. Rhyll sea pens	Rhyll segment	Sediment	Sessile invertebrates on sediment; sea pens, bryozoans, sponges, ascidians (Blake et al 2013)
17. French Is. macroalgae (north)	Upper north arm	Mixed	Macroalgae including mixed red and <i>Caulerpa</i> spp. beds (Blake et al 2013)
18. French Is. macroalgae (south)	Rhyll segment	Mixed	Macroalgae/seagrass including mixed green algae beds
19. San Remo rhodolith beds	Rhyll segment	Mixed	Rhodoliths (Harvey & Bird 2008)
20. Rhyll green algae beds	Rhyll Segment	Mixed	<i>Caulerpa</i> spp. macroalgae beds (Blake et al 2013)

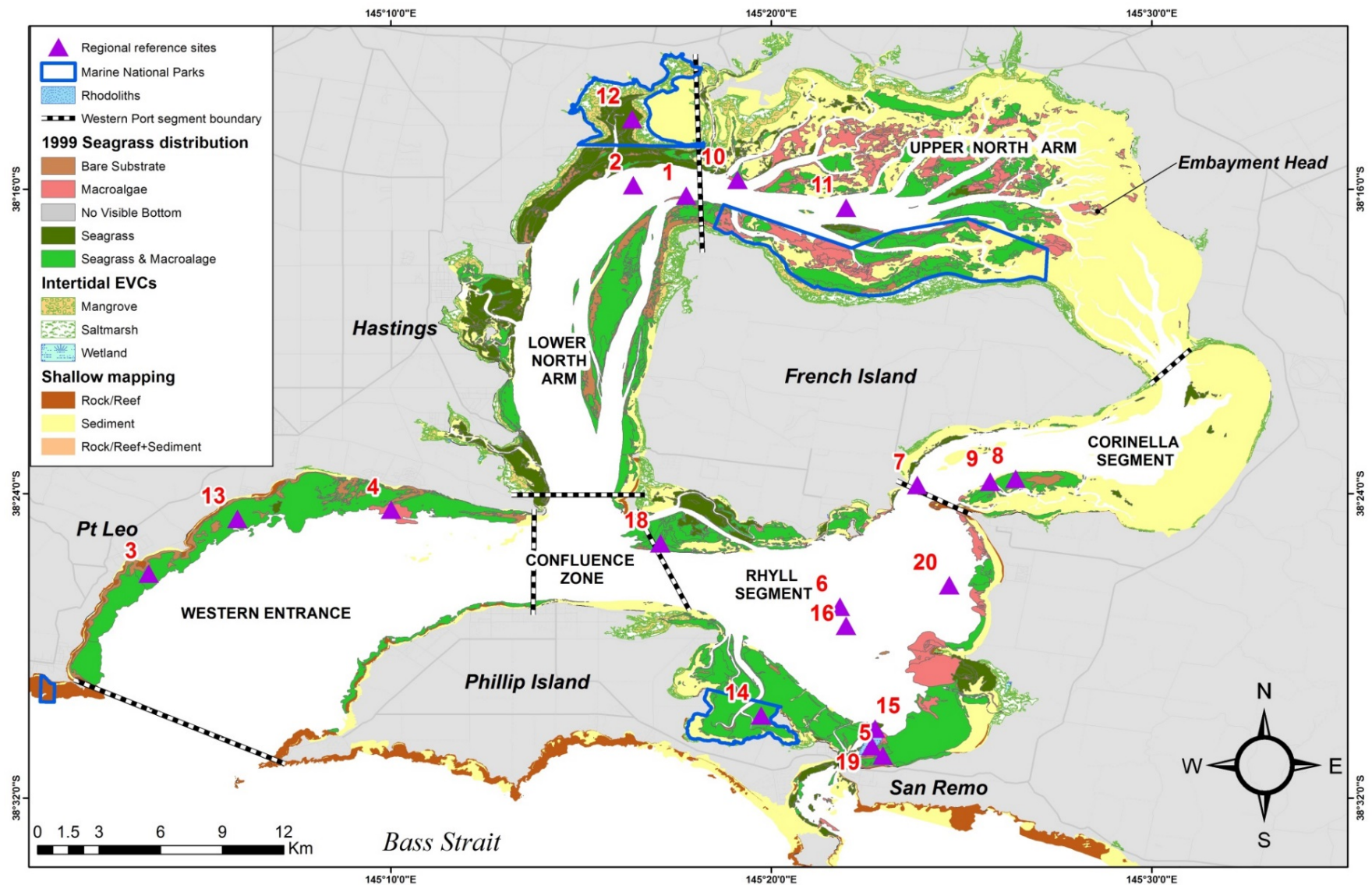


Figure 14. Proposed location of regional reference sites for Western Port. Site numbers cross-referenced site descriptions – see Table 5. Please note additional sites within the lower north arm will be prioritised following MBES data acquisition.

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