Western Port Bryozoan Reefs Research Project

Report 2: Reef Type and Extent

Report to La Trobe University, AGL and Port Phillip and Westernport Catchment Management Authority

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Non-technical Executive Summary

A unique bryozoan reef biotope has been formally described in Western Port, Victoria, Australia for the first time. The Western Port Bryozoan Reefs Research Project is a multidisciplinary project funded by AGL, The Port Phillip and Westernport Catchment Management Authority, La Trobe University and Fathom Pacific Pty Ltd. The project is investigating various abiotic and biological aspects of the reefs and the present report describes reef type and extent.

Multibeam echosounding combined with underwater observation and imagery surveys have identified a bryozoan biogenic reef biotope that has not been recorded anywhere else in Victoria and indeed appears to be unique globally. The bryozoan reefs occupy an area of 1.74 km^2 and occur in three 'cells'. There appear to geomorphic and depth-related controls on the distribution of bryozoan reefs in this area which are expected to limit the maximum possible extent of suitable habitat. The Western Port bryozoan reefs occur in two different types: linear reefs and patch reefs. The size and vertical relief of the mounds in the linear reefs are among the largest recorded in the literature.

While other kinds of bryozoan biogenic habitats have been recorded elsewhere, there are several features of the Western Port reefs make them unique:

- Shallow depth;
- Dominance of delicate, fenestrate (net-like) colonies;
- Linear reef morphology;
- Silty inter-reef sediment.

Bryozoan biogenic reefs are vulnerable to physical damage, sediment, algal invasion and other threats. In Western Port, physical damage from recreational fishing, sedimentation and risk of introduced marine pests are the main pressures on the bryozoan reefs.

This report outlines the typology and extent of the reefs, which are two foundational aspects of establishing the management and monitoring requirements of this biotope, which are in the so-called Rhyll Segment of East Arm and within the Western Port Ramsar site but outside any existing Marine Protected Areas. The conservation significance of this biotope is described and the Western Port Bryozoan Reefs Research Project aims to list the biotope under the Victorian Flora and Fauna Guarantee Act 1988.

Other studies of the Western Port Bryozoan Reefs Research Project that are currently underway and will be the subject of separate partner reports are:

- Invertebrate fauna;
- Application of citizen science monitoring;
- Fish biomass;
- Age and growth of bryozoans.

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1. Introduction

1.1. Bryozoan and other biogenic reefs

The following types of biogenic reefs have been documented in temperate waters of southern Australia:

- Shellfish reefs: Historically extensive oyster and mussel reefs in Port Phillip Bay.
- Worm tube reefs: Apparently more common in Atlantic Ocean, but in Victoria, *Galeolaria caespitose* forms thickly encrusting clumps and beds.
- Ascidian reefs: In Victoria, aggregated solitary ascidians of several species form biogenic beds in Port Phillip Bay, Corner Inlet and Gippsland Lakes.
- Sponge-clump reefs: Aggregated sponges forming biogenic beds have been identified in tide-swept channels in Port Phillip Bay and Corner Inlet.
- Temperate coral reefs: *Plesiastrea verispora* forms coral-dominated beds in Port Phillip Bay.
- Bryozoan-rich beds: Bryozoan-rich beds have been described from the Great Australian Bight (see Table 1), the continental shelf around Tasmania and Bass Strait, and Bathurst Channel, Tasmania.

Bryozoans are a diverse group of invertebrate colonial animals, with about 5700 extant (Horowitz and Pachut, 1994) and 15,000 fossil species (Amini 2004) recognised. Areas of high bryozoan density are known from just 54 sites globally (Wood et al. 2012), only three of which were known in Australian waters prior to the present study. Individual bryozoan colonies create structural microhabitat for other fauna (Wood and Probert 2013) and this ecological function and service is enhanced when colonies combine to form biogenic reefs (Bradstock and Gordon 1983). Bryozoan biogenic reefs are formed by so-called hard bryozoans (calcified skeleton). Soft bryozoans that can be in locally high abundance in the lower strata of kelp-dominated exposed open coast reefs apparently do not form biogenic reefs.

Bryozoan biogenic reefs appear to be a feature of temperate zones, although Wood et al. (2012) noted bryozoan biogenic habitat through a latitudinal band between 13˚N and 23˚S. Bryozoan biogenic habitat tends to occur in the lower limits of the photic zone or in shallow turbid waters where they are not out-competed by light-dependent algae, potentially allowing for larger colony sizes to be attained and diverse epifaunal communities to form (Bock et al. 2018). This light-based exclusion/competition scenario is analogous to tropical scleractinian corals and algae as light and competition basis. Favourable growth conditions for bryozoans are cited as water masses consisting of adequate nutrient supply and abundant supply of unarmoured phytoplankton that are the primary food source for bryozoans (James et al. 2008).

Several of the reports of bryozoan 'reefs' actually relate to bryozoan-rich rock formations (e.g. Abrolhos Shelf, Brazil (Bastos et al. 2018) and bryozoan-rich fossil bioherms (Cuffey 1977; Ernst and Königshof 2008) and sediments (e.g. Tasmanian continental shelf, James et al. 2008). So-called bryozoan "sands" are a feature of the southern Australian shelf sediments that are cited as Holocene in origin (James et al. 2008). Fenestrate bryozoan forms typically dominate these Holocene sands although fine branching forms can be locally abundant in deeper water (generally below 80 m) where wave energy is low.

The bryozoan reef mounds on the Otago Shelf, New Zealand, are true extant bryozoan reefs, forming emergent mounds of various species (see Table 1). Wood et al. (2012) cite 50 mm as the size at which heavily-calcified bryozoans become habitat-forming. The authors cite growth rates of 0.8 to 5 mm per year, indicating that extant bryozoan biogenic reefs likely establish on the scale of decades. As reported herein, epibenthic colonies in the Western Port bryozoan reefs attain sizes of some 2,000 mm in radius and 500 to 1,200 mm in vertical relief, suggesting century-scale age visible reef.

1.2. First indications of the Western Port bryozoan reefs

Non-reef forming bryozoans occur throughout Western Port (Figure 2), often associated with circalittoral reef but also occurring as individual colonies among seagrass and Caulerpa beds, epiphytic on seagrass leaves, and growing on jetty pylons.

Perhaps the first indication of the potential presence of bryozoan reef comes from the historic records of the Western Port or mud oyster (*Ostrea angasi*) dredge fishery that was prevalent in Western Port from 1820s to 1920s. Initially, the key commodity was lime made from the shells to produce mortar (Hannan and Bennett 2010). From about the 1850s-1860s, demand for consumption of oysters increased as did the fishing intensity. Hand-hauled dredges were used to catch some "*12,000 to 14,000 dozen oysters per week…from 20 to 25 boats…*" (Hannan and Bennett 2010) (Figure 1). Historic records indicate that fishers interacted with abundant bryozoan reefs:

> *"Lumps of live coral were often brought up, so big that they blocked the dredge mouth. These lumps were broken up and thrown back. The coral was live and full of sealife, worms, octopus etc."* (Hannan and Bennett 2010).

Indeed, the interaction between oysters and bryozoans is intriguing given the observations made in our studies of oysters occurring on bryozoan reefs and the presence of a dense shell layer ~10-20 cm under the sediment surface at bare sediment sites.

Table 1 Notable extant bryozoan habitats.

Location	Depth	Reef morphology	Dominant species	Reference
Otago Shelf, New Zealand	45-130 m	Habitat-forming bryozoans on gravels and sands, forming biogenic 'thickets'	*Cinctipora elegan, Hornera robusta, Hippomenella vellicata, Adeonellopsis* spp., *Celloporina grandis*	Wood and Probert 2013, Batson 2000, Batson and Probert 2000; Jones 2006; Probert et al. 1979;
Foveaux Strait, New Zealand	17–38 m	Biogenic reefs with ~ 20 cm relief	*'Schizoporella' spectabilis* and *Micropora* sp. *Penetrantia parva*, *Opaeophora lipida, Microporella agonistes*, *Beania elongata*, *Penetrantia irregularis*	Cranfield et al. 2003, 2004
Tasman Bay, New Zealand	10–35 m	*C. agglutinans* clumps up to 0.5 m in vertical height and *H. vellicata* foliaceous honeycomb structures to 0.15 m height	*Celleporaria agglutinans*, *Hippomenella vellicata*	Bradstock and Gordon 1983
Abrolhos Shelf, South Atlantic Off Brazil	2–35 m	Erect mushroom-like reef formations.	Skeletal remains of multiple species dominating concretions	Bastos et al. 2018
Ligurian Sea, northwestern Mediterranean	11–22 m	Mounded, seabed covering reef formations	*Pentapora fascialis* (non-fenestrate species)	Cocito et al. 1998
Cap de Creus, northwestern Mediterranean	61–225 m	Bryozoans on coarse sands and gravels and canyon head	113 species of erect, encrusting frontal budding, shell epibionts, and dead skeleton	Madurell et al. 2013
Tasman Bay, New Zealand	10-35 m	Mounded, seabed covering reef formations of	*Celleporaria agglutinans* and *Hippomenella vellicata* (non-fenestrate species)	Bradstock and Gordon, 1983
Foveaux Strait, New Zealand	20-60 m	Reef 'swards' aligned perpendicular to current flow	*Cinctipora elegans*	Cranfield et al. 2013
Bathurst Channel, Tasmania	5–20 m	Not reported but presumed individual colonies	Species and morphotypes not reported	Barrett et al. 2007
Lacepede Shelf, southern Australia	~30–250 m	Seafloor encrustation, branching colonies, erect colonies	*Adeona* spp., *Membranipora* spp., *Crisia* sp., *Cellaria pilosa.* >200 species present on shelf	Bone and James 1993, Hageman et al. 1995
Coorong Lagoon, southern Australia	-	-	Intergrown bryozoa and serpulids	Bone and Wass 1985
Great Australian Bight, southern Australia	100–240 m (paleodepths)	Bryozoan-rich biogenic mounds. Pliocene–Pleistocene period	*Celleporaria* spp., nodular-arborescent, fenestrate, flat robust branching, encrusting, delicate branching	James et al. 2004
Bass Strait and Tasmanian shelf, southern Australia	~30–400 m	Bryozoan-rich shelf sediments.	Erect-flexible articulated zooidal and articulated forms, erect-rigid flat-robust branching and fenestrate forms, encrusting forms.	James et al. 2008
Joulters Cay, Bahamas	1–4 m	Historic bryozoan-rich reef formations now over-grown predominantly by corals. Reefs are circular, elongate, triangular or notched in plan view, to a max. of 10 m across.	*Cleidochasma*, *Holoporella*, *Parasmittina*, *Rhynchozoon*, *Schizoporella*, *Smittipora*, *Steginoporella*, and *Stylopoma*	Cuffey et al. 1977

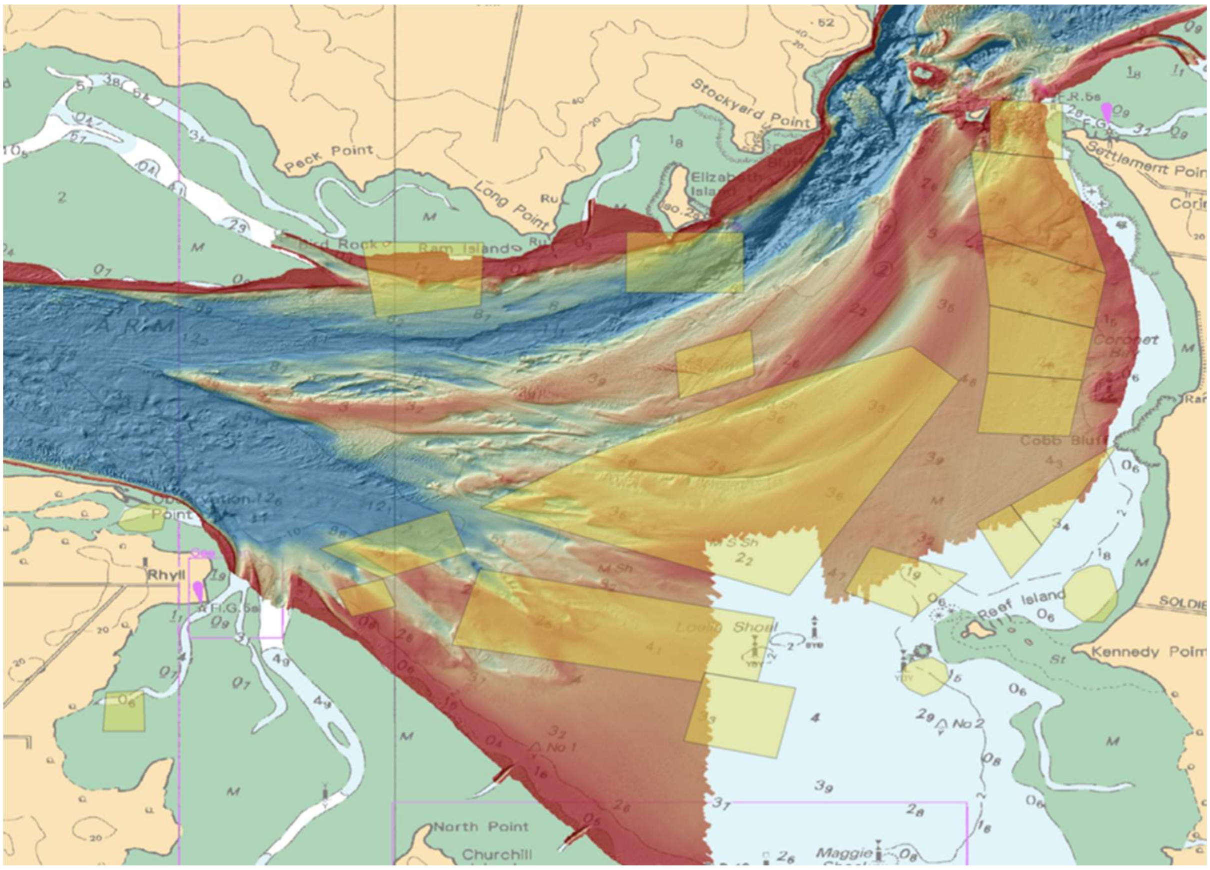
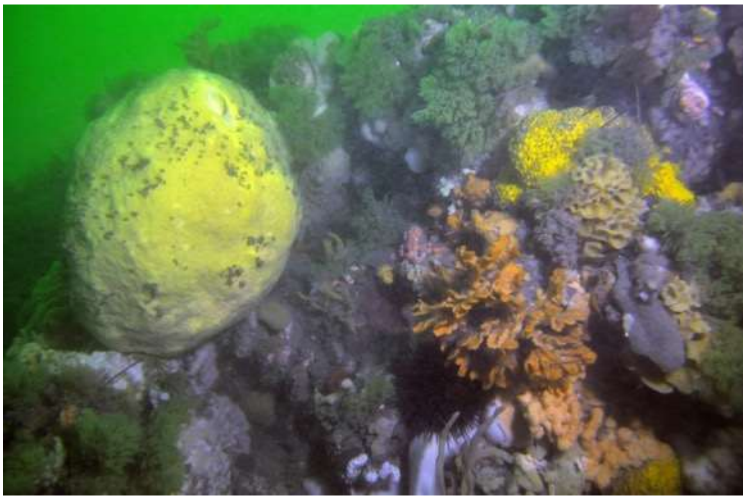


Figure 1. Location of historical oyster dredging licence areas (yellow polygons) active in the 1920s. Source: oyster dredging areas digitised from Hannan and Bennett (2010).

The general bryozoan reef area has locally become known to commercial and recreational fishers as "The Corals", probably named for the fragments of bryozoan skeleton that resemble coral which is sometimes present on anchors and sinkers when retrieved. Today it is known as a productive recreational fishing area for which GPS coordinates are available in the grey literature. Commercial finfish netting in Western Port ceased in December 2007 and the remaining commercial line fishing ceased shortly thereafter.

The first scientific indications came from Blake and Ball (2013) who employed towed camera transects and noted "isolated colonies", comprising "patches of low and high profile broken, and solid reef colonised by dense bryozoans and sparse sponges". The significance of the discovery was not appreciated until the same towed video footage was reviewed in 2016 during a biotope classification project by the Department of Environment, Land, Water and Planning (DELWP) (Fathom Pacific 2016). The 2016 biotope mapping made use of multibeam bathymetry collected in 2009 which showed, at a coarse resolution, characteristic seabed textures that required further examination, instigating the Western Port Bryozoan Reef Project.

(a) Woolamai Pinnacle (30 m water depth)



(b) Crawfish Rock (25 m water depth)

(c) Stony Point Jetty (4 m water depth)

Figure 2. Examples of non-reef-forming bryozoan colonies in Western Port and surrounds.

1.3. Objectives

The Western Port Bryozoan Reef Project was developed as an academic–industry–community partnership with the following broad aims with respect to the bryozoan reefs in general:

1. Quantify the typology and extent of the bryozoan reefs;
2. Document the diversity of bryozoans and co-occurring species;
3. Investigate and quantify threatening processes and vulnerability;
4. Establish conservation values; and
5. Engage citizen scientists and community stakeholders.

The present report relates to objective 1. The specific aims of this study were:

- To complete high resolution multibeam echosounding of the bryozoan reefs;
- To complete ground-truthing surveys and inform a description of the reef environments;
- To assess the aerial extent of bryozoan reef habitat;
- To make recommendations for monitoring and conservation.

2. Methods

2.1. Study area

The bryozoan reef area is located between French Island, Corinella and Rhyll in water depths ranging between 5 and 12 m, Western Port, Victoria, Australia (Figure 3). Suspected reef areas were visualised in multibeam bathymetry commissioned by the Port of Hastings Development Authority in 2009 (horizontal resolution of 2.5 × 2.5 m). Remote Operated Vehicle (ROV), drop/drift camera (Figure 4) and SCUBA dive investigations were conducted in the key areas of interest between December 2017 and February 2020 to define the reef areas for new high-resolution multibeam echosounding (MBES). Approximately 1.5 hours of ROV footage and 10 SCUBA dives were made in the more linear reef zone of the north cell and in addition 3 hours of drop camera footage was obtained (Figure 5). Diver collections of small representative samples for taxonomic purposes. The biological samples and imagery were donated to National Museum Victoria.

Bryozoan reefs were found to occur in three sectors, coined north cell, middle cell and south cell. Due to the sequencing of funding and limitations of funding precluding MBES throughout the entire area of Western Port, core areas in each of these cells were identified and surveyed, with a second survey expanding on the first to cover all of the suspected reef area.

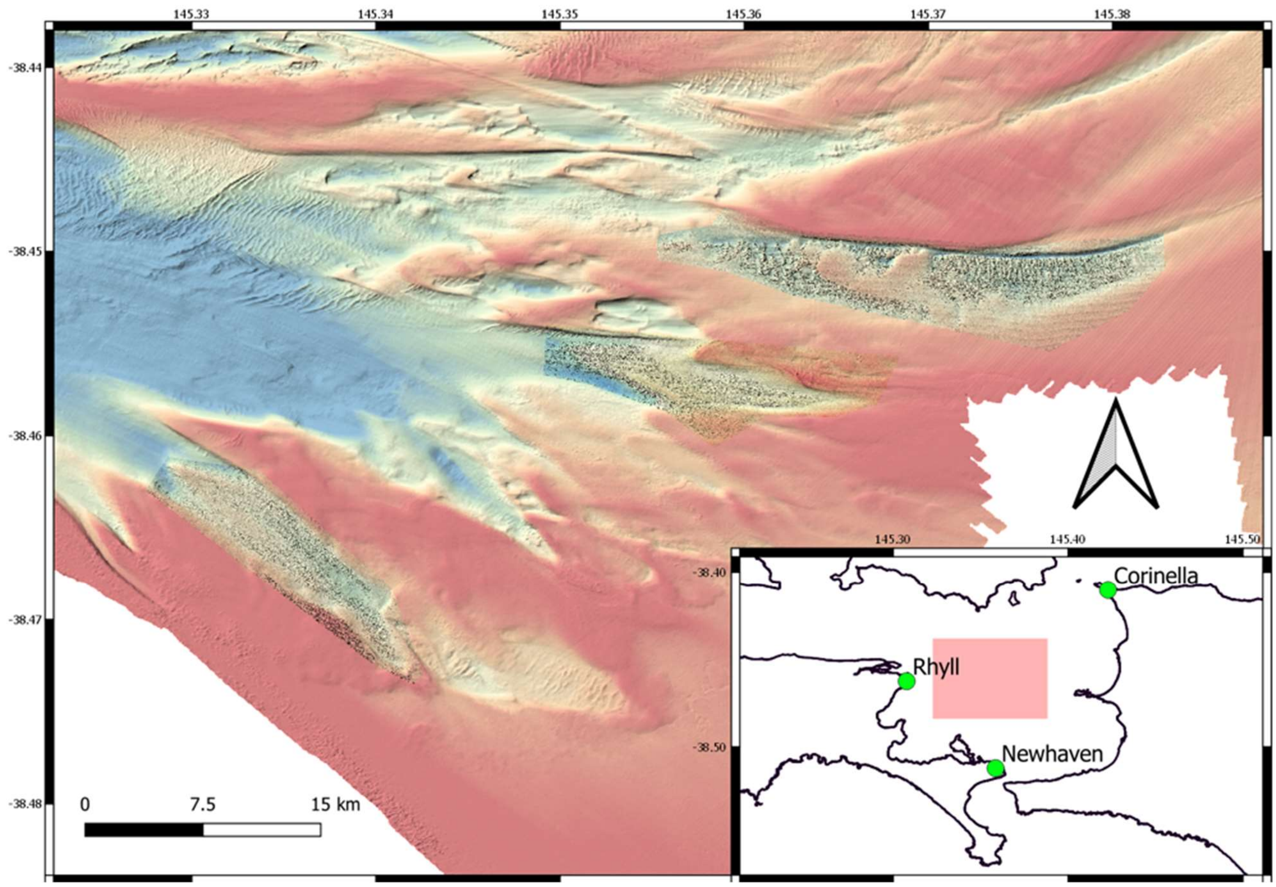


Figure 3. Location of the study area

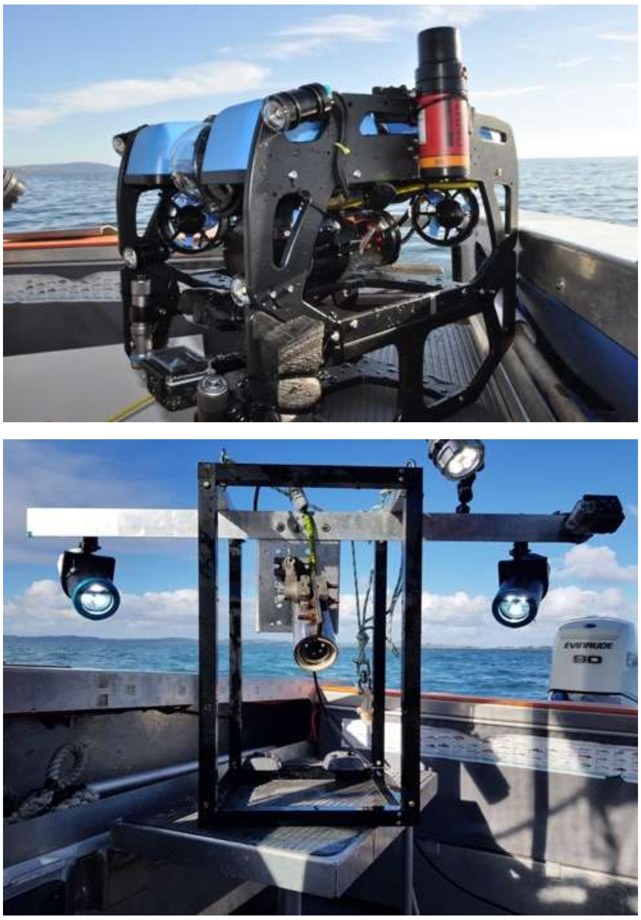


Figure 4. Remote operated vehicle (top) and drop/drift camera (bottom) used for ground-truthing surveys.

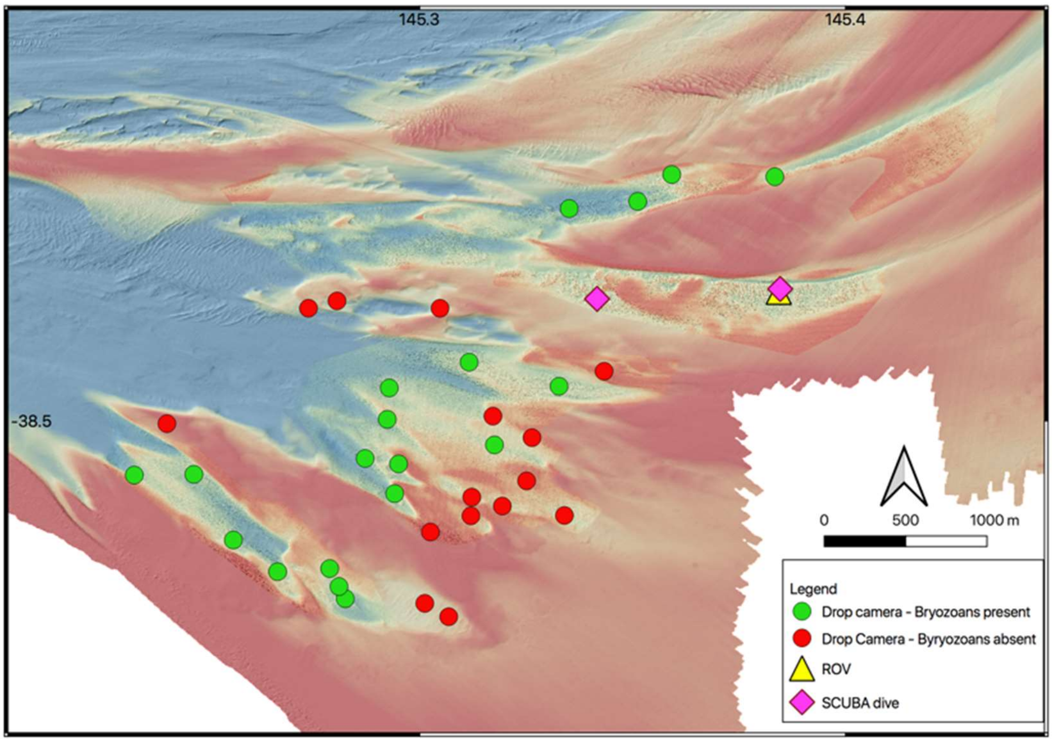


Figure 5 Imaging groundtruthing sites. Note bryozoans are present and ROV and SCUBA dive locations

2.2. Multibeam surveys

Three target bryozoan reef areas were surveyed in the north cell, middle cell and south cell, for a total area of 6.4 km^2 at a resolution of 0.5 x 0.5 m (Figure 6).

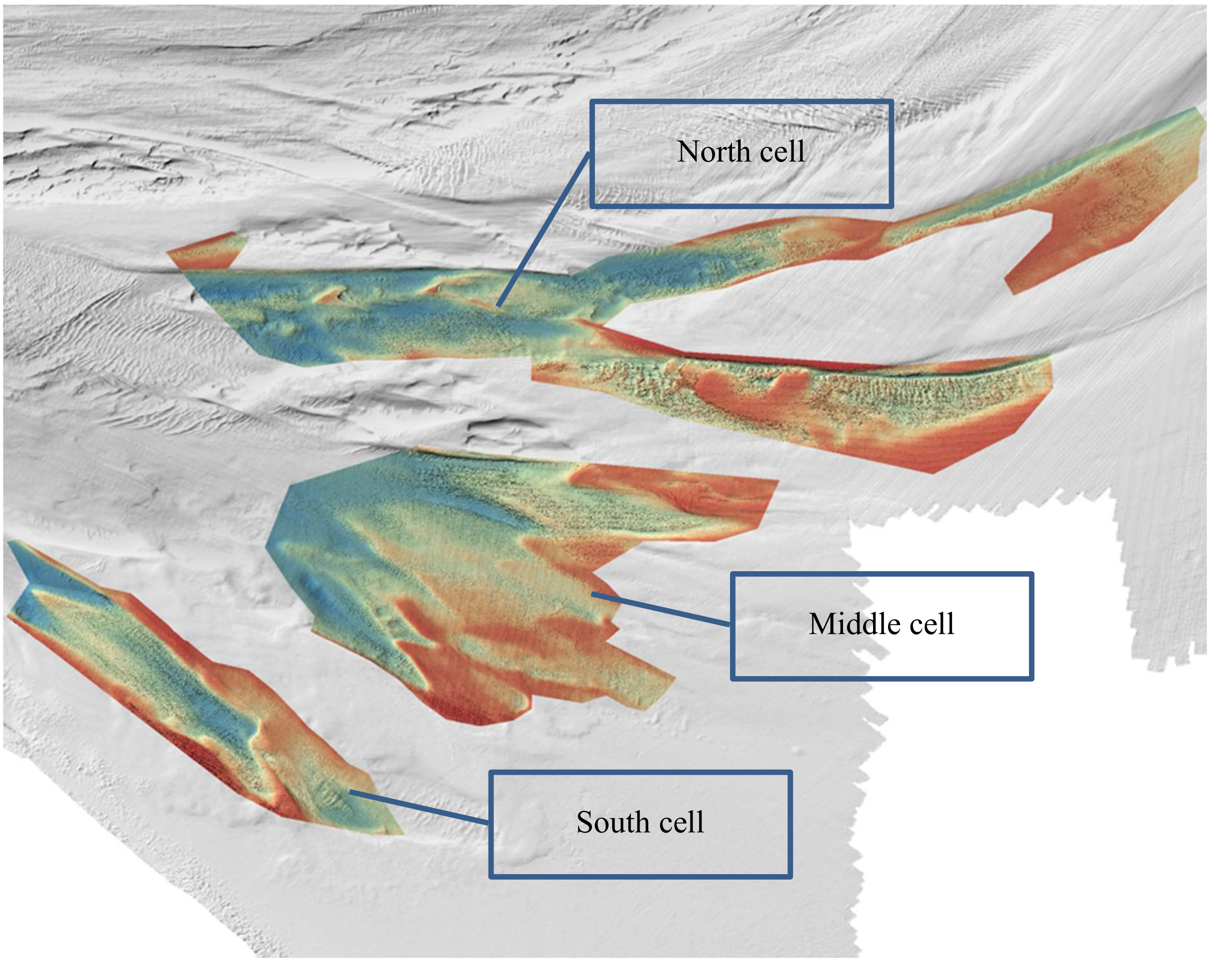


Figure 6 Multibeam survey areas (AGL and PP&WP CMA-funded coverage).

Multibeam echosounding was completed by Total Hydrographic Pty Ltd using an R2Sonic® Dual Head 2020 multibeam system (340, 400 kHz frequency). Positioning was achieved with an Applanix® POS MV Wavemaster system with the real-time kinematic (RTK) satellite position validated against the Victorian Permanent Survey Mark “Bittern PM 259”. The multibeam soundings were corrected to Lowest Astronomical Tide (LAT). Data processing used the Hypack® 2020 system and digital elevation models for the survey areas were produced at a horizontal resolution of 0.5 m × 0.5 m.

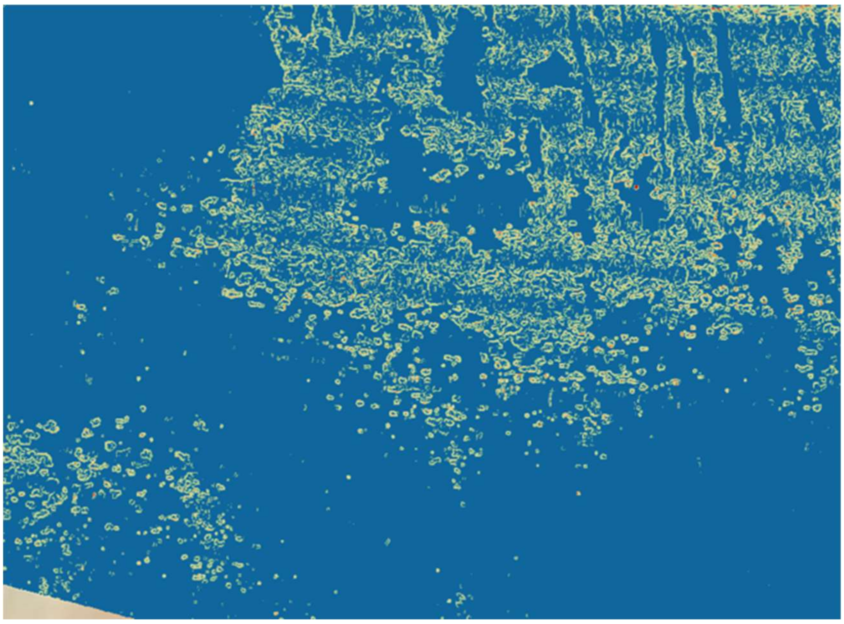
The multibeam surveys were completed over the period 9–10 October 2019 and 11–14 Feb 2020. Reports of survey are presented in Attachment 1.

2.3. Reef area calculation

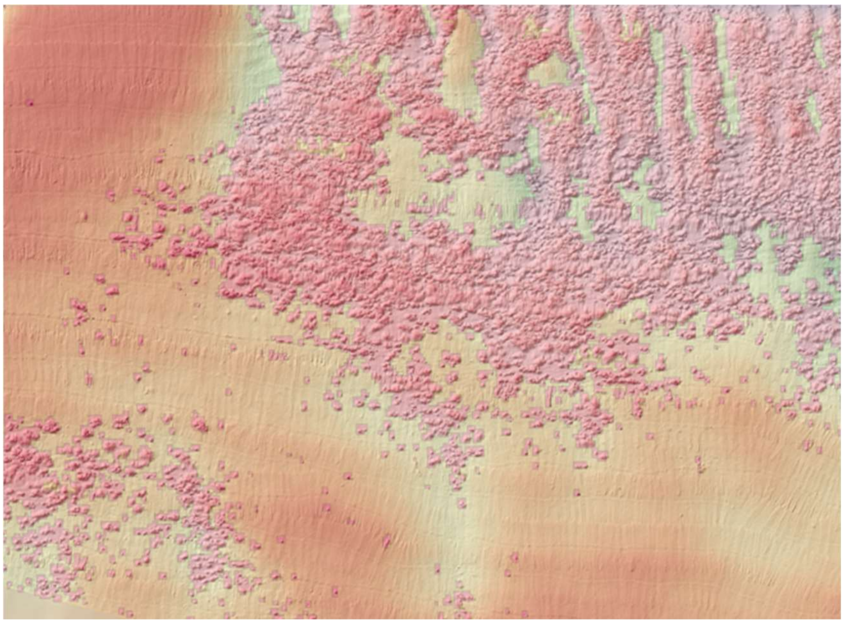
Bryozoan reefs were clearly visualised in the bathymetry mosaics in each of the three cells. It was considered important to develop an objective reef area estimation that minimises subject human interpretation. Therefore, an automated GIS-based routine was developed to 'detect' and polygonise reef areas. Habitat modelling was not deemed necessary as the reef features are spatially constrained and detectable. After experimenting with a number of terrain morphology tools to delineate the morphology and texture of reefs, a simple workflow using slope which reliably detected the linear reefs and circular morphology of individual colonies as follows:

1. Apply slope calculation on bathymetry raster.
2. Bryozoan reefs are detected as circular features with slope ≥ 7 degrees in the north cell and 5 degrees in the middle and south cell. Extract rasters of those slope values and convert to a binary raster that was a proxy for 'reef' and 'non-reef' pixels. As will be discussed below, in the middle and south cell, there was a depth control of bryozoans and an additional rule of "> 4 m" was applied to the slope-based detection.
3. Grow the resultant slope raster to omit fragmented cells using the GRASS tools:
    a. r.grow function –1 m cell size.
    b. r.neighbors function – neighbourhood window of 5 cells.
4. Covert raster to polygon.
5. Use delete holes tool to fill annuli features using a minimum cell area of 1 m^2.
6. Use Fix Geometries tool to correct polygon spatial inconsistencies.
7. Visually check and manual polygon clean-up of obvious errors by overlaying on vertically exaggerated hill-shaded bathymetry.

The detections were checked for continuous reef beds and patch reefs (Figure 7). This detection method may over- or under-estimate actual reef area, but error in the calculation is kept consistent and allows for standardised reef extent monitoring over time.



(a) Slope (colours present slope angle)



(b) Reef polygons (pink) overlaid on bathymetry

Figure 7. Example of the slope raster (a) and the polygonised linear and patch reef generated by the reef detection workflow (b) in the north cell.

3. Results and Discussion

3.1. Reef-forming species

Taxonomic collections confirmed that the reefs are composed of three intermingled bryozoan species: *Triphyllozoon moniliferum*, *Triphyllozoon munitum* and *Celleporaria foliata* (Figure 8). The *Triphyllozoon* species are fenestrate, mounded colonies while *C. foliata* is a non-fenestrate species forming plate-like colonies that can be mounded, spreading or encrusting. In-water observations suggest that the two *Triphyllozoon* species are present in approximately equal proportions and these two species are more dominant (making up an estimated 80–90% of the reefs), than *C. foliata*.

(a) *Triphyllozoon moniliferum*

(b) *Triphyllozoon munitum*

(c) *Celleporaria foliata*

Figure 8. Three species comprising the predominant structure of the Western Port bryozoan reefs.

3.2. Reef types

3.2.1. Linear reefs

Observed only in the north cell, these reefs consist of continuous reef mound rows, aligned in an approximately north-south orientation, separated by tracts of sediment. The reef rows range from ~ 3 m in width to some 30 m in width.

The linear reef features occur in three zones in the north cell, interrupted by a sediment shoal (Figure 9 and Figure 10). This sediment shoal is present in the 2009 bathymetry in addition to this new bathymetry and so does not appear to be a recent feature or to have changed significantly since 2009. The northern edge of the contiguous reef rows coincides with a distinctive gully feature and a steep slope leading to a raised bank (see Figure 9). Due to the high density of habitat-forming bryozoans in the linear reefs, these are considered to harbour the highest matrix-associated biodiversity. The linear reefs are imaged in Figure 11.

The vertical relief of the linear reefs rows ranges from approximately 50 cm to 120 cm above the surrounding sediment. Water depths in the linear reef zones ranges from approximately 4.8–6 m. The sediment shoal separating the linear reef zones has a depth of approximately 4 m, and bryozoan reef is observed around the western-southwestern margin of that shoal feature. As will be described below, there is an apparent depth-related demarcation of bryozoan reefs which may explain the absence of bryozoans on this shoal feature. Alternatively, the absence of bryozoans on the shoal may be related to the temporal sequencing of the appearance of this feature in the evolution of the system.

Diver observations and core sampling revealed that the sediment tracts between the reef rows are composed of very fine silt particles with depauperate infauna. One hypothesis for this is that the baffled structures of the reefs form localised slowing of near-bottom currents, favouring the settlement and trapping of fine particles that are otherwise transported in strong tidal flows. The multibeam bathymetry showed signs of sediment processes, with potential sediment accretion on the eastern sides of reef rows (Figure 12).

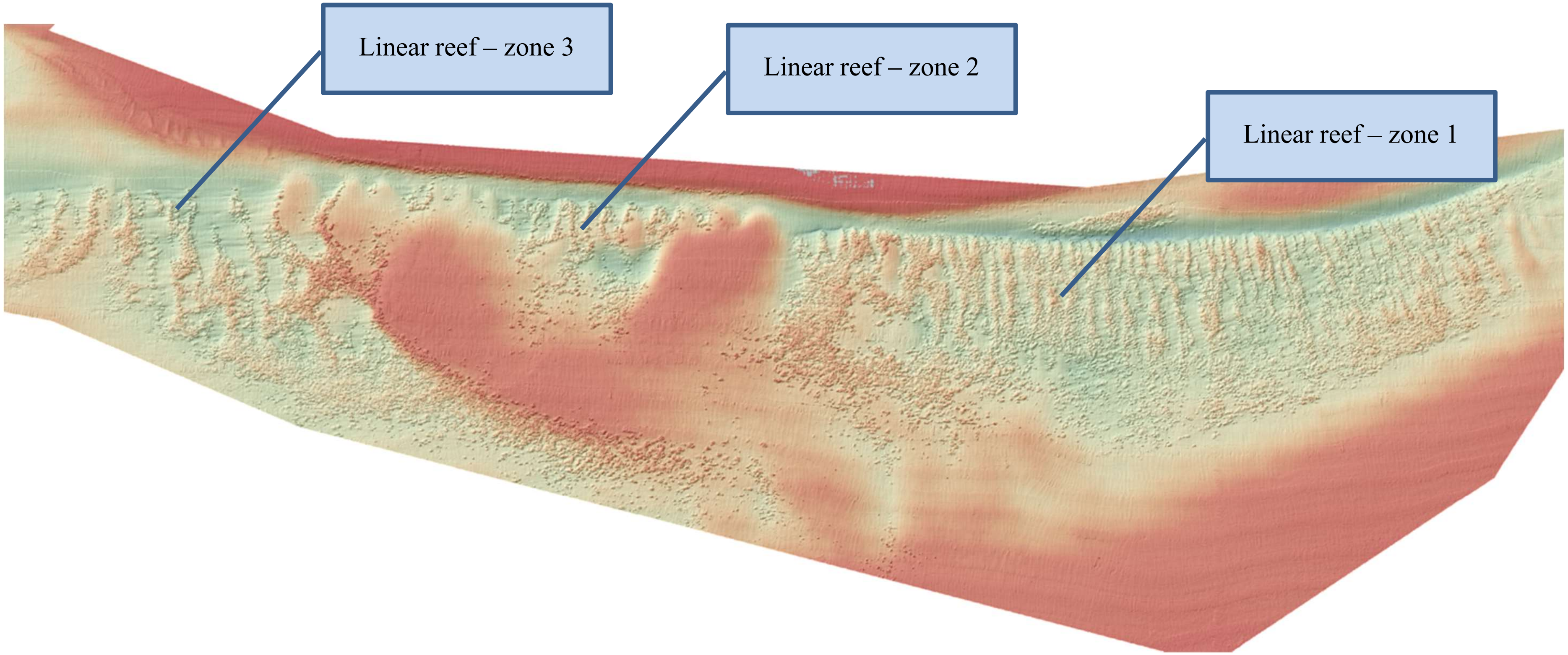


Figure 9 Linear bryozoan reef formations in three zones of the north cell. Colours represent depth range 3.3 to 7.3 m.

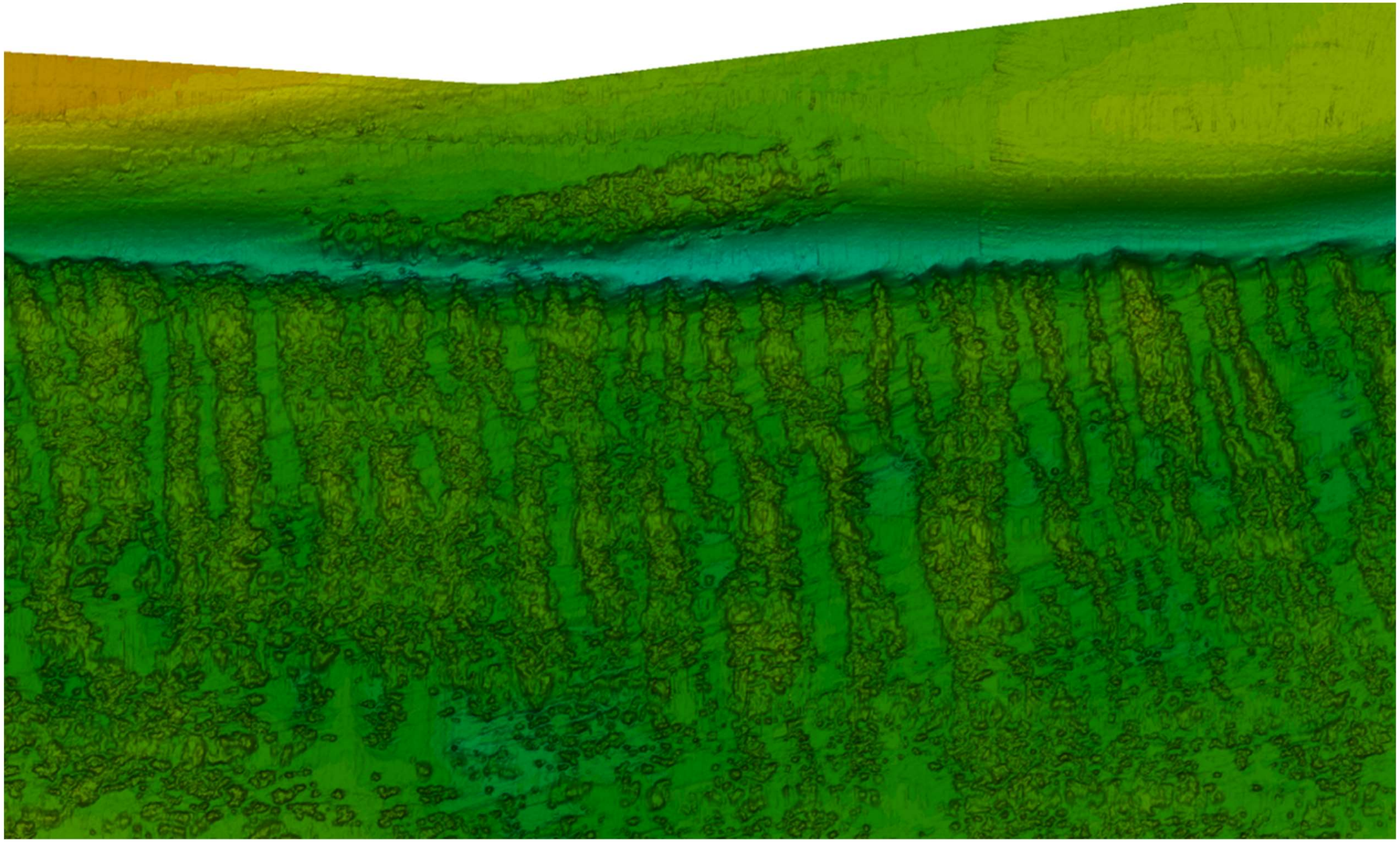


Figure 10 Detailed view of a linear reef segment in zone 1, showing the northern boundary associated with a gully feature. Note patch reef on ascending slope to the north of the gully.

Figure 11 Images from the linear reef – north cell, zone 1. Note cavities and gaps in colonies that may reflect anchor damage. Note presence of tufted fine red algae (potentially seasonal) that may be competition with bryozoans

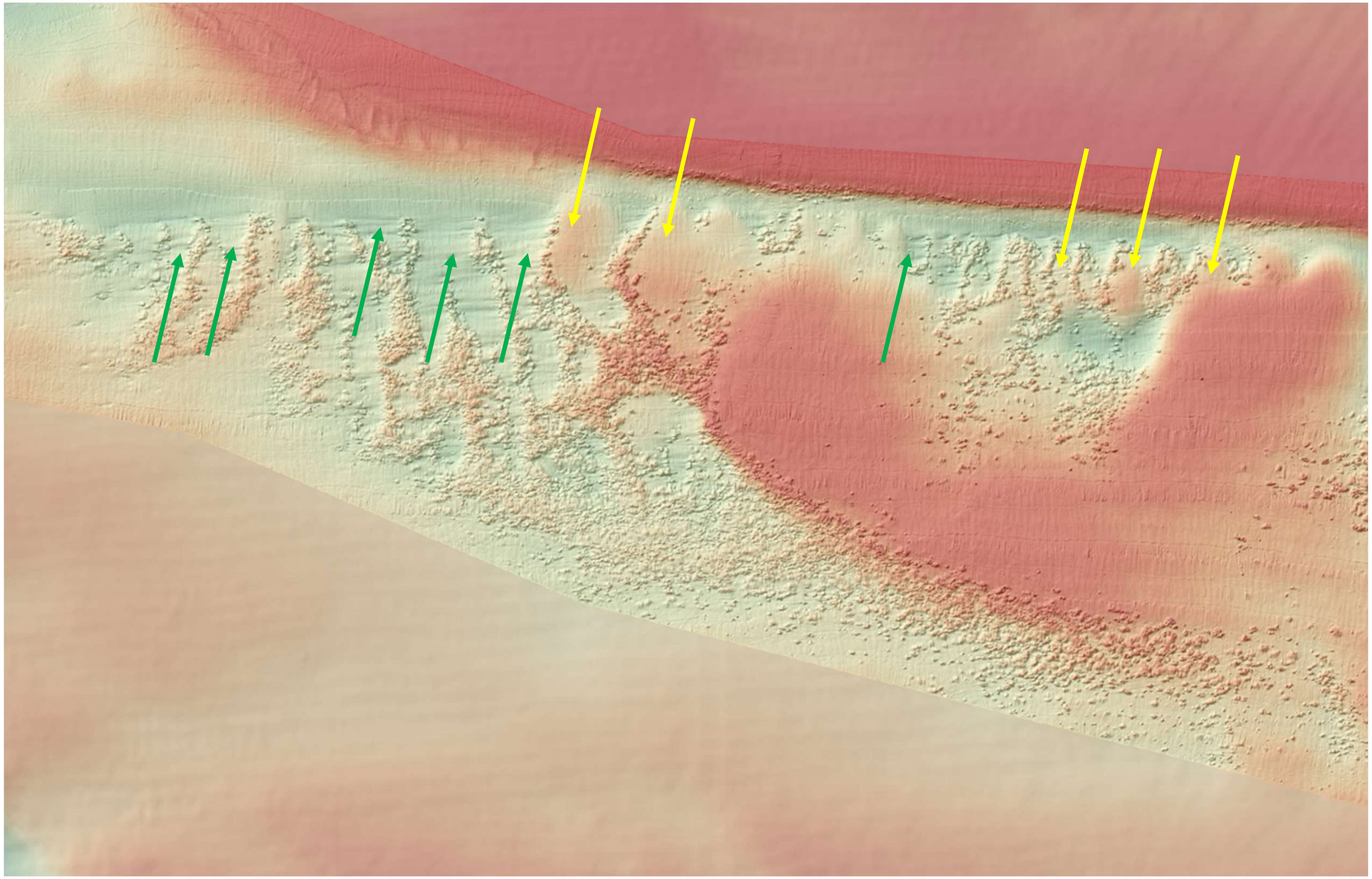


Figure 12 Potential sediment accretion on eastern sides of reef rows (yellow arrows) and scour (green arrows) on western sides. Colour gradient represents depth range 3.3 to 6.5 m.

3.2.2. Patch reefs

Bryozoan patch reefs are observed in the northern, middle and southern cells. Patch reefs occur in water depths ranging from 8.5 to 4.5 m (Figure 13, Figure 14, Figure 15). In some areas, patch reefs are concentrated to form localised continuous patches that take a different form to the linear reef features described above.

Ground-truthing of patch reefs has not been as thorough as that for the linear reefs in the present study and field visual observations have been hampered by low visibility. However, field observations suggest that individual reef patches represent ‘islands’ of enhanced localised biodiversity of matrix-associated fauna compared to the surrounding sediment beds.

The discovery of patch reefs in the south cell significantly expanded the distributional range of bryozoan reefs. Furthermore, discovery of patch reefs in the far north and east portions of the north cell represent new findings. Some patch reefs in the north cell are associated with apparent remnant, or newly forming, linear reef features (see Figure 15).

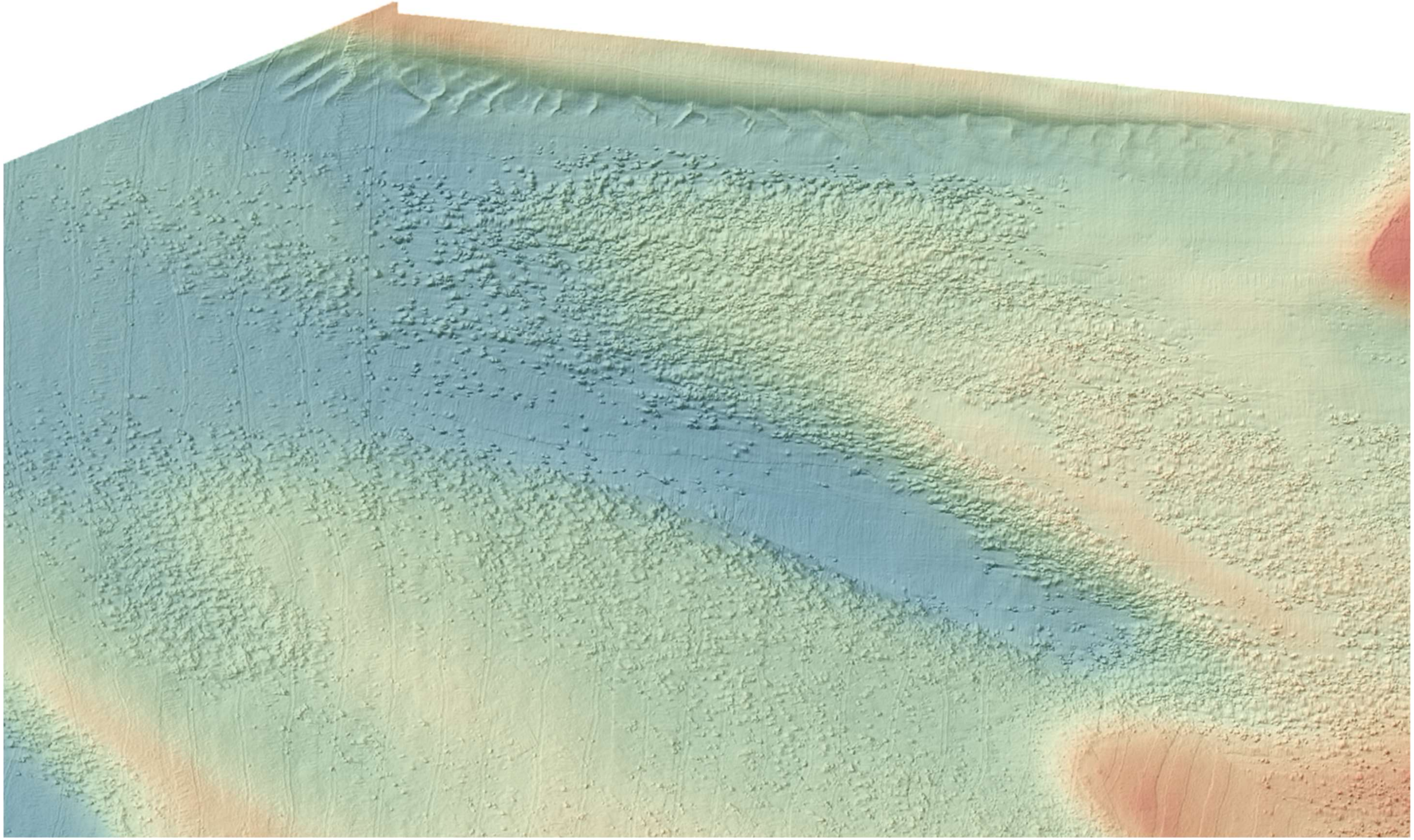


Figure 13 Detail of patch reefs in the middle cell. Note dense patches may form areas of continuous biogenic bed.

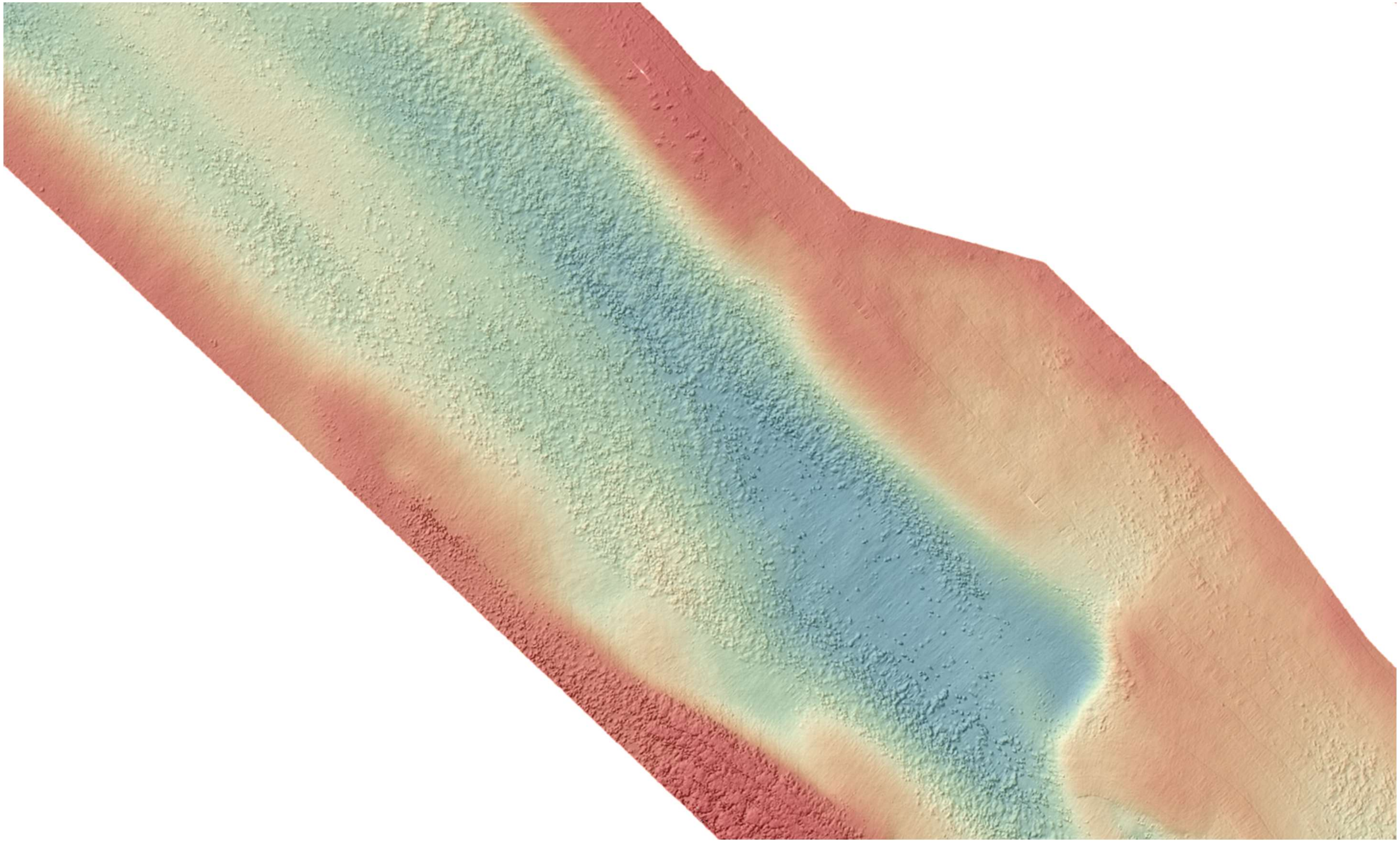


Figure 14 Detail of patch reefs in the south cell. Note dense patches may form areas of continuous biogenic bed. Seabed texture in the shallow (red) southwest corner of image is *Zostera*-Caulerpa (seagrass-algae) biotope.

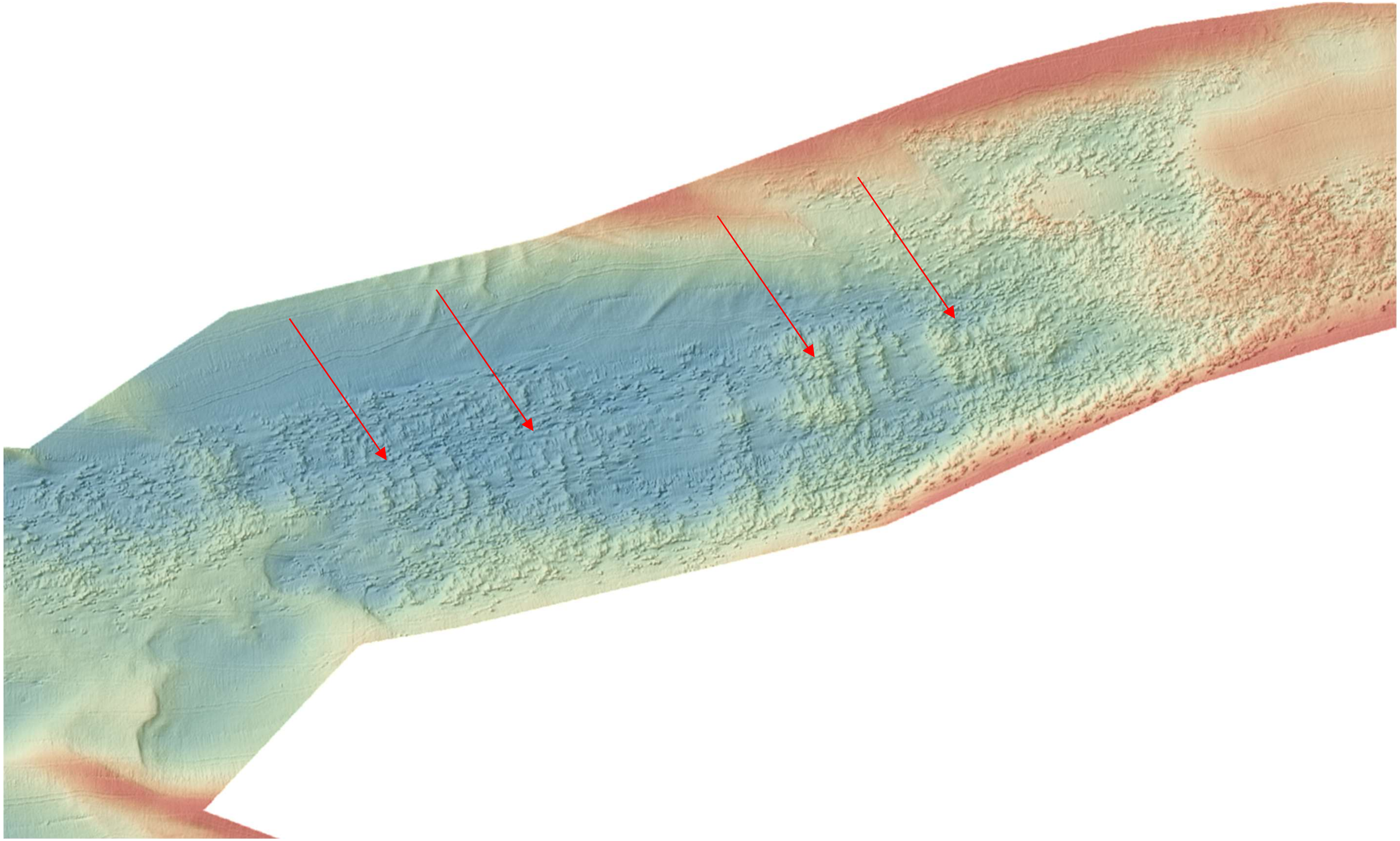


Figure 15 Detail of patch reefs in the north cell. Note the possible remnants of linear reef features (red arrows).

3.3. Bryozoan reef extent

Bryozoan reef covers a total area of 1.74 km^2 (Table 2) and is depicted in Figure 16.

Table 2 Western Port bryozoan reef extent

Area	Bryozoan Reef Extent
North cell	0.78 km^2
Middle cell	0.91 km^2
South cell	0.05 km^2
Total	**1.74 km^2**

A key unknown at this point is what the ecological interactions are between the bryozoan mounds and the surrounding sediment which will dictate what buffer should be considered around bryozoan colonies to spatially define the reef. Therefore, the appropriate ecological and management spatial units are unknown at this stage. While the analysis method estimated area coverage of bryozoan reef mounds (Table 2), perhaps a suitable management unit for the bryozoan reefs should be considered as an area that encompasses neighbouring sediments within the geomorphic units harbouring the bryozoan mounds (e.g. yellow bounding boxes in Figure 16 totalling 6.4 km^2).

This approach of considering a broader 'suitable habitat' approach to spatial depiction of the bryozoan reefs is reflected in the literature on bryozoan reefs on the Otago Shelf (Probert et al. 1979; Wood and Probert 2013). This approach is potentially more appropriate from a marine spatial planning perspective as management at the scale of individual reef reefs (meter scale) may not be feasible. However, at the level of biological monitoring, smaller spatial scales are more appropriate given the high resolution of the acoustic monitoring techniques and high accuracy of spatial referencing of underwater imagery available today. Cocito et al. (1998) took this fine-scale approach to monitoring individual bryozoan mounds in the Ligurian Sea (Mediterranean), which is most appropriate to investigate reef health and sub-lethal impacts.

A multi-scale approach to the consideration of 'reef extent' and monitoring (see Section 4 below) is recommended at this time so that monitoring can be scaled correctly to the ecology, while spatial management and communication can be suitably targeted.

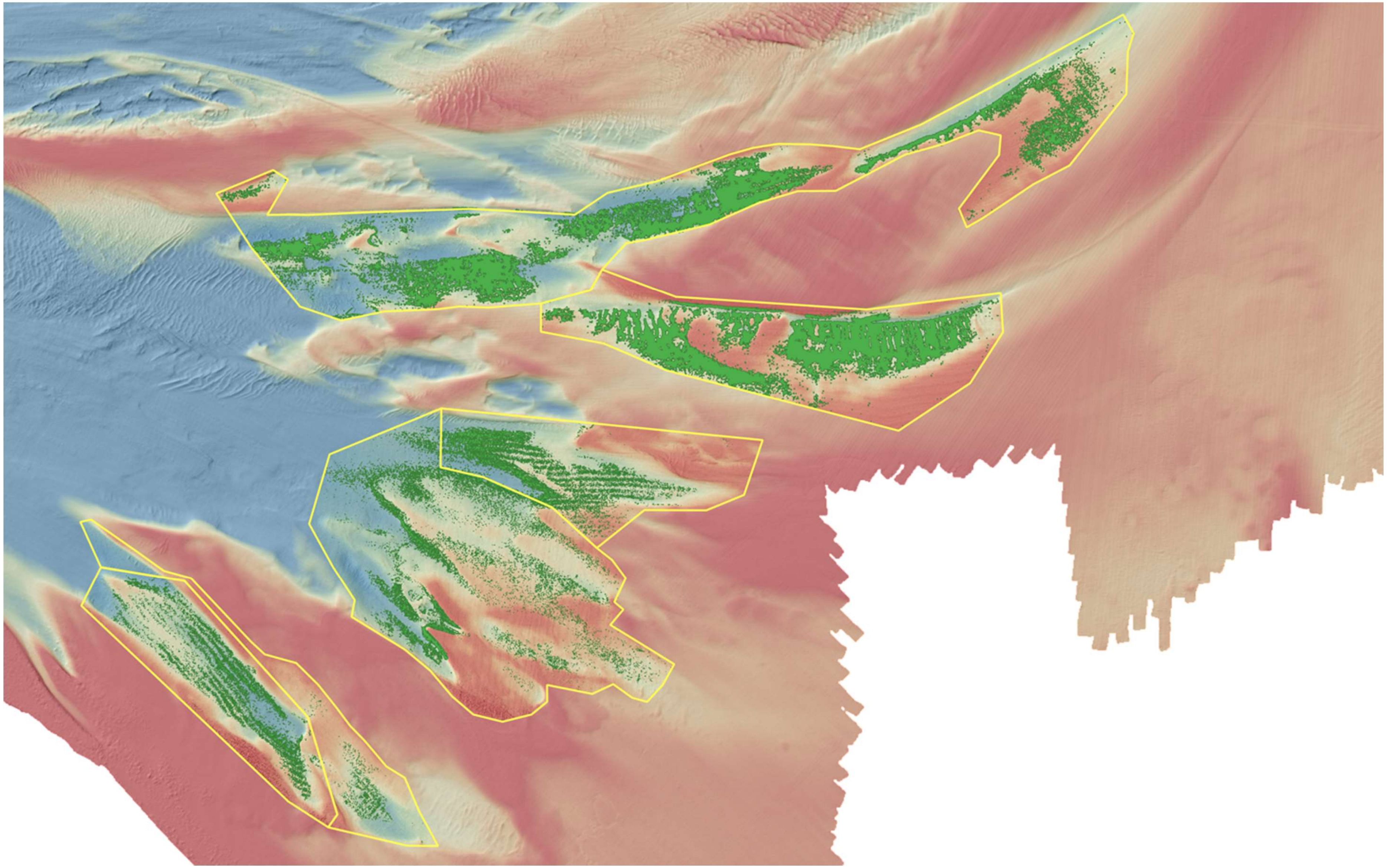


Figure 16 Total extent of detected bryozoan reef (green polygons) and the surveyed area (yellow polygons)

3.4. Ecophysical setting and controls

Located in the East Arm of Western Port (in an area termed the “Rhyll Segment” by Harris et al. (1979)), the bryozoan reefs occur in seafloor depressions at the terminus of sub-channels that impinge on a large eastern subtidal bank (Figure 16). However, these channels are not the main deep channels that area exposed to strong current flow, such as the channel immediately to the south of French Island. Rather, this area of East Arm lays within a body of water that is influenced by the mixed flows from eastern entrance and Rhyll Channel to the south and the main East Arm Channel to the north, in addition to draining of shallow intertidal banks to the east and south (Figure 17).

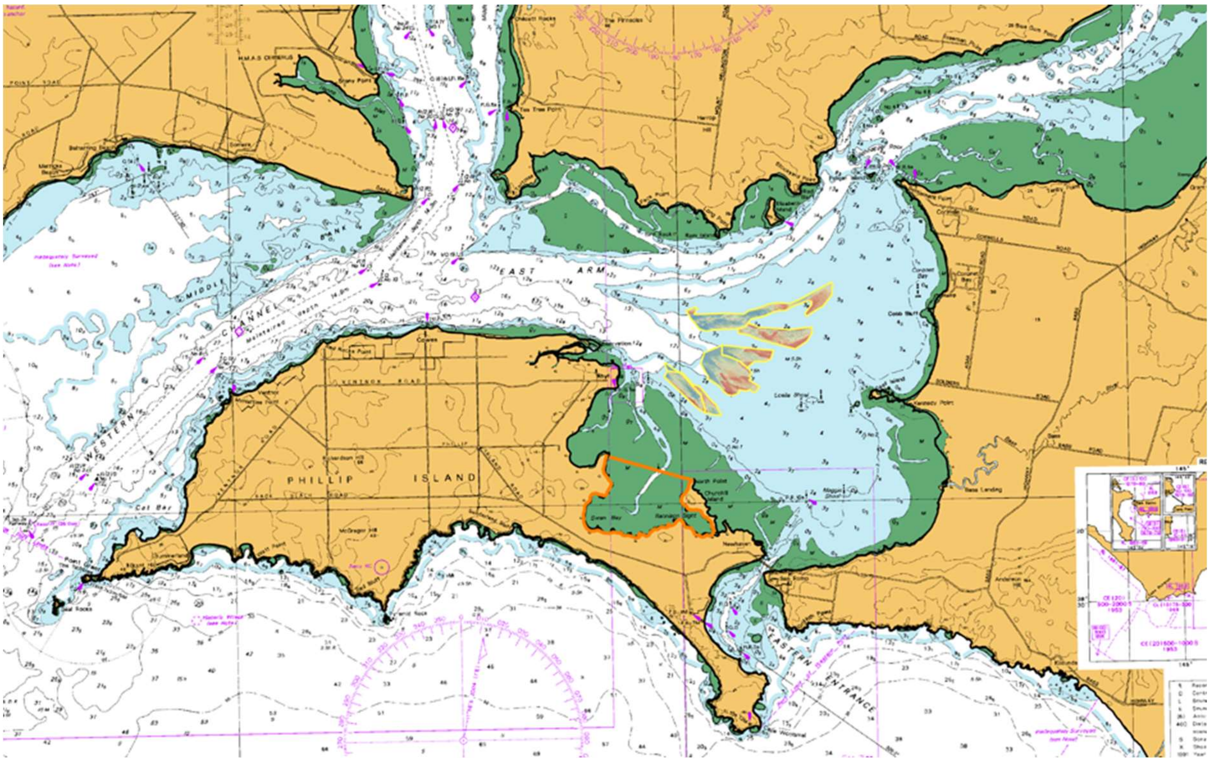


Figure 17. Location of the bryozoan reefs in context to channels and banks in East Arm, Western Port. Orange outline is Churchill Island Marine National Park (background image is Australian Admiralty Chart AUS150).

Underwater and surface observations at the site indicate that tidal currents are slowed in this area compared to the neighbouring main channels and there is significant eddying. Harris et al. (1979) noted that currents in the so-called Rhyll Segment do not display the symmetry that is characteristic of other sites and is characterised by a generally counter-clockwise circulation pattern. Linear bryozoan ‘swards’ in Foveaux Strait, New Zealand are orientated parallel to the peak tidal current direction (Cranfield et al. 2003). The approximately north-south orientation of the linear reefs in Western Port may be associated with the pattern of northerly movement of flood tide currents from eastern entrance, along the eastern coast towards Corinella reported by Harris et al. (1979).

These conditions of reduced and eddying current flow would be conducive to the settlement of larvae and establishment of fine fenestrate lamellae in newly established colonies that would likely to be prohibited in the strong current flow in main channels. These conditions may also serve to retain or enhance phytoplankton production, the main food source of bryozoans (James et al. 2008; Cranfield et al. 2003).

Subtle depth controls on bryozoan distribution were observed and these are exemplified in the middle cell. Bryozoan reefs in the middle cell were generally constrained to the depth range 4.5 to 8.5 m (Figure 18). Bryozoan reefs generally did not encroach onto the subtidal banks to the east and south of the middle cell shallower than 4.5 m. *Zostera nigricaulis* seagrass and *Caulerpa geminata* algae (apparently seasonal) beds occur on these banks and where very sparse bryozoans were detected shallower than 4.5 m, they were observed to be interspersed among seagrass. Few bryozoans were detected deeper than 8.5 m in the middle cell. Interestingly, this ecophysical model of bryozoan reefs bordering the offshore extent seagrass beds is reflected in the historical accounts from the oyster dredging fishery, in which fishers reported highest oyster catches at the offshore extent of seagrass.

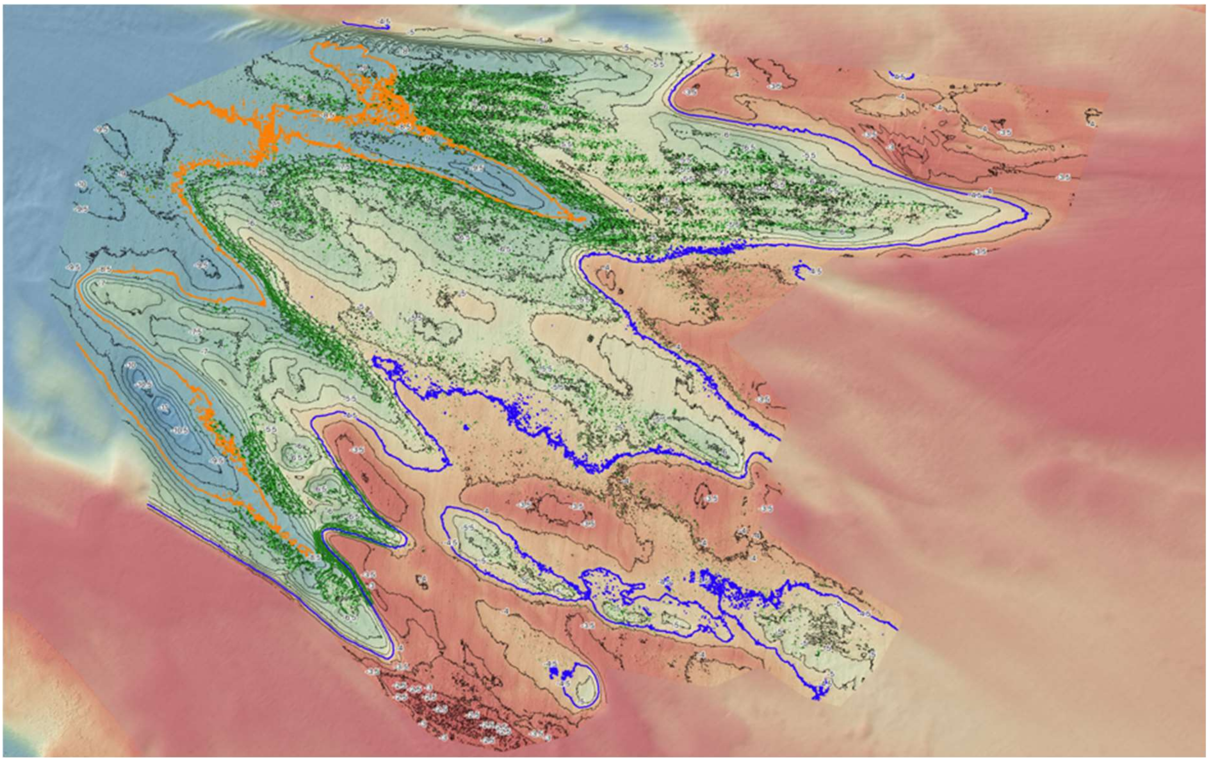


Figure 18. Bryozoan reefs in the middle cell (green) in relation to depth contours (orange = 8.5 m, blue = 4.5 m).

On the Lacepede Shelf, South Australia, Hageman et al. (1995) cited primary factors of nutrients, temperature, water chemistry, environmental stability, substrate, competition, and secondary factors of water depth and currents as the main abiotic drivers of bryozoan distributions. On the Tasmanian continental shelf, Amini et al. (2004) noted bryozoan morphotype associations with water depth, energy regimes, sedimentation rate and substrate type, with fenestrate and foliose forms occupying deeper water where energy and sedimentation rates were low and where hard substrate is more abundant. The presence of shallow, dense growth of fenestrate bryozoan forms in the Western Port reefs is therefore unique, but probably related to the low wave and current energy at this location. Over the spatial scale and depth range of the Western Port bryozoan reefs, nutrient supply, water chemistry, temperature and water circulation patterns are presumed to be constant. Therefore, the depth-related patterns observed may be related to competition with/exclusion from seagrass and *Caulerpa* at the shallow end of their distribution. Limitations to distribution at the deep end of the distribution may be related to increased current exposure and substrate differences.

3.5. Co-occurring mud oysters

In-situ camera and diver observations have confirmed that mud oyster (*Ostrea angasi*) occur closely associated with the bryozoan reefs. Anecdotally, there appears to be a correlation between the presence of oysters and *Celleporaria foliata*, with oyster conglomerations forming amongst the skeletal matrix of that bryozoan species, although it has been observed in combination with the other bryozoan species.

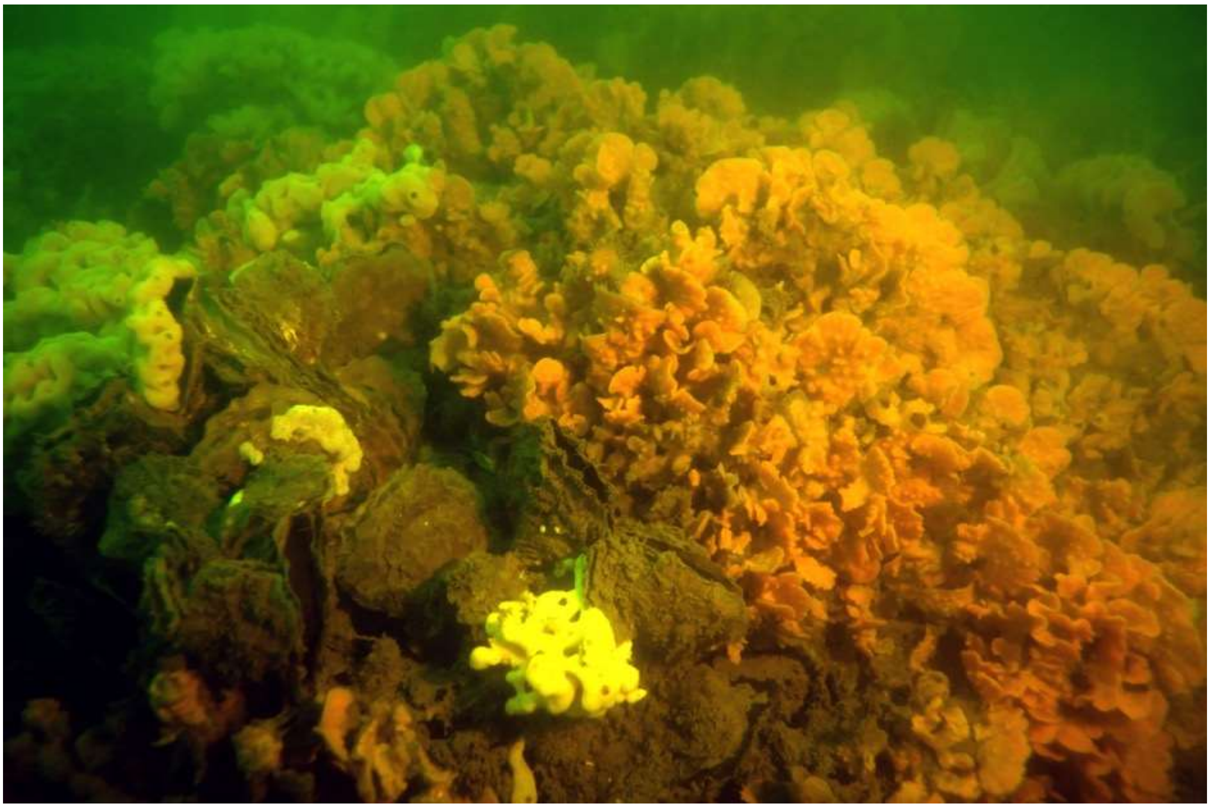


Figure 19. Mud oysters (*Ostrea angasi*) amongst *Celleporaria foliata* and sponges.

Oysters (*Ostrea chilensis*) were also observed in association with bryozoan reefs in Foveaux Strait, southern New Zealand (Cranfield et al. 2004). There is wide recognition of the ecosystem services of bivalve biogenic beds and considerable efforts and financial investment in rehabilitating oyster reefs in Port Phillip Bay and other bivalve reefs globally. The Western Port mud oyster fishery was over-fished and eventually closed and it could be that the 'nuisance' to dredgers caused by the bryozoan reefs afforded some protection. Today, this stronghold of Western Port mud oysters associated with the bryozoan reefs further adds to the biogenic habitat-forming structure and conservation significance.

3.6. Uniqueness

The Western Port bryozoan reefs are unique in Victoria, with no biotope of this kind reported anywhere else in state waters, based on the ~40,000 biotope records from underwater imagery held in the Department of Environment, Land, Water and Planning's (DELWPs) CoastKit biotope atlas. No extant bryozoan reefs of this kind are reported elsewhere in Australia to the author's knowledge. Globally, the Western Port bryozoan reefs are unique in several ways:

1. Species composition

Western Port bryozoan reefs are dominated by *Triphyllozoon moniliferum* and *T. munitum* which are delicately fenestrate, mound-forming species. Bryozoan biogenic reefs in the Ligurian Sea (Mediterranean) (Cocito et al. 1998) and in New Zealand (Bradstock and Gordon 1983; Cranfield et al. 2003, 2004; Wood and Probert 2013) are composed on non-fenestrate mounded, branched or encrusting colonies.

2. Depth

The depth of the Western Port bryozoan reefs is considerably shallower than most other recorded sites of Bryozoan reefs or bryozoan-rich sediments in southern Australia and New Zealand (see Table 1). The Western Port reefs are within the range of reported presence of bryozoans in Bathurst Channel, Tasmania, and within the range that individual bryozoan colonies have been recorded in Western Port and Port Phillip Bay, but no other biogenic reef habitat has been reported in this range in Australia.

The depth range of the Western Port bryozoan reefs approximates, but is shallower than, that recorded for the Ligurian Sea (Mediterranean) bryozoan reef mounds and the bryozoan-rich reef pinnacle structures in Brazil (see Table 1). The depth range of the Western Port reefs is similar to that recorded for the Joulters Cay (Bahamas) historic bryozoan reefs (now overgrown with corals).

Several authors have identified an apparent relationship between fragile morphotypes and wave energy as a likely explanation for the presence of these forms in deep water on the continental shelf (Amini et al. 2004; James et al. 2008), while also recognising that localised conditions may lead to typically "deep water" forms occurring in shallow water. The presence of large foliose mounds of fenestrate species, with vertical relief up to 1.2 m in shallow water is globally unique to the Western Port bryozoan reefs to the author's knowledge.

3. Extensive linear mound formations with high vertical relief

The Western Port bryozoan reefs form extensive linear mounds in the north cell, with a vertical relief of up to 1.2 m. No other extant bryozoan biogenic reefs with this morphology have been recorded in Australia. The Western Port reef formations are most similar to those recorded by Cocito et al. (1998) in the Ligurian Sea (Mediterranean). The Ligurian Sea bryozoan reefs are composed of *Pentapora fascialis*, a non-fenestrate but similarly lamellate and mound-forming species.

4. Silty inter-reef sediment and seagrass–*Caulerpa* association

Western Port bryozoan reefs, particularly those in the north cell, are interspersed with very fine silty sediments, potentially driving important sediment trapping, mobilisation and transport regimes. Siltation-induced necrosis was reported on bryozoan reef mounds in the Ligurian Sea (Cocito et al. 1998).

Bryozoan reefs in the middle and south cell are bordered by seagrass and *Caulerpa* beds. This may establish biotope associations that are important to the maintenance of reefs.

3.7. Conservation Significance

Many of the ecosystem servives provided by bryozoan biogenic reefs are directly related to the existence of living and structurally complex skeletal matrix. This biogenic habitat is particularly well formed in the Western Port bryozoan reef system, with linear reef mounds and patch reefs vastly exceeding the 5 cm in height proposed by Wood et al. (2013) as the minimum to be classed as 'habitat-forming'. The co-occurrence of mud oysters in the Western Port reefs further add to the ecosystem services and conservation significance of the biotope. Furthermore, the enhanced invertebrate biomass associated with the reef compared to neighbouring habitats renders the reefs biodiversity 'hot spots' in the bay that likely drive localised enhanced vertebrate abundance (under investigation through partner studies).

Fragmentation of intact linear reef is considered a key threat to the Western Port bryozoan reefs. Cranfield et al. (1999) documented the deleterious impacts of the dredge oyster fishery on bryozoan biogenic habitat in Foveaux Strait, New Zealand, and the apparent rarity of recolonisation after cessation of direct impacts. The loss of shellfish biogenic reefs in Victoria has been documented (Ford and Hamer 2016) and significant investment is now being made to restore these lost biogenic habitats in Port Phillip Bay and elsewhere around the world (Gillies et al 2018). The high vulnerability of bryozoan reefs to physical damage, the complications and expense of biogenic reef rehabilitation and the apparent limited ability for recolonisation of bryozoans after fundamental substrate alteration (Cranfield et al. 1999) suggest that conservation efforts and education should be focussed on protecting the reef that currently exists.

Impacts to bryozoan reefs can be summarised as:

1. Physical damage to structures from anchoring and bottom fishing;
2. Terrigenous sediment input and processes of sedimentation–remobilisation, sediment sorting and accumulation, and scouring;
3. Water quality, litter and other contamination;
4. Competitive or other deleterious interactions with other species (e.g. native algae, marine pests, disease, bioeroders);
5. Climate change and associated changes in water physicochemistry, circulation and productivity.

There are several features of the Western Port bryozoan reefs that contribute to its vulnerability:

Limited area extent: The Western Port bryozoan reefs have a very limited distribution range and extent, and they are spaced closely to one another. The potential mechanisms impacting reefs in one area are therefore likely to apply to all areas. Given that local within-reef recruitment and growth are likely to be essential to the maintenance of the reefs, and surrounding substrates may be unsuitable for new reef establishment, deleterious may be irreversible.

Colony foundations and substrate availability: A key vulnerability of the Western Port bryozoan reefs is the hypothesised scenario that, due to changing land use practices and altered sediment regimes in the bay, the substrate currently occupied by the bryozoans is fundamentally different to that first colonised some centuries ago. The conceptual model of bryozoan reef formation in this area is that bryozoans settled on a historic coarse sand/gravel/shell bed, a substrate type known to be favoured by bryozoans (Cuffey et al. 1977), that is different to the surface sediments that occur today. This hypothesis is developed from the following observations:

- From a geomorphic perspective, the linear arrangement of reefs in the north cell mirrors the linear arrangement of sand waves in other parts of the East Arm. Sand waves are known to cause grain size sorting and it is possible that the original settlement substrate of the bryozoan reefs was associated with sorted larger granules in linear formations.
- Diver observations indicate that the very fine silty muds immediately adjacent to linear reefs in the north cell are extremely unconsolidated contain numerous shards of broken, dead bryozoan skeleton.
- Hand-coring in more distal sediments to the south of the north cell revealed a dense, impenetrable shell layer, some 10–20 cm below todays sediment surface, indicating the presence of a historic sediment bed that is significantly different.

Therefore, the hypothesis is that the current visible expression of bryozoan reefs is anchored to a degree, but generally epilithic, growing upward in step with changing sediment conditions over the last 200 years such that there is no anchoring to the parent substrate. As such, the principle concern for conservation is that if the reefs are deleteriously impacted, the modern substrate is not conducive to recolonisation as it is very fine silty muds in the north cell and muddy sands in the middle cell. As demonstrated in the New Zealand case, substrate alteration appears to significantly diminish recolonisation potential. Continued growth and maintenance of the Western Port bryozoan reefs, therefore, may be strongly reliant on colony extension from existing mounds.

Age and growth: The age and growth of the bryozoan reefs is currently under investigation in a partner study. Given the literature values, it is presumed that bryozoans are slow-growing and the age of the Western Port reef structures are on the scale of centuries. The maximum potential age of the bryozoan reefs is limited by the age of the bay itself, which is presumed to be approximately 10,000 years old, coinciding with the Holocene sea-level rise encroaching through the Western Entrance (Gill, 1973; cited in Marsden et al. 1979).

Fenestrate species forming foliose colonies: The Western Port bryozoan reefs are dominated by very fragile, foliose colonies formed by fenestrate species. This is a unique characteristic that sets these reefs apart from the mound-forming reefs in the Mediterranean and New Zealand.

Easily discoverable recreational fishing locations: Commercial fishing no longer occurs in Western Port, but there is an active and growing recreational fishing sector. The reefs are easily discoverable in the grey literature and are within reach of a wide range of fishing craft with modern fishing echosounders. The site is generally regarded to be a productive fishing area. Anchoring practices in Western Port generally involve long lengths of chain to cope with the strong tides normally experienced in the bay and it is common for fishers to move between fishing spots regularly during a session. Wind, currents and short slack water periods likely act to increase the potential for physical damage from chain and rope beyond the footprint of the anchor itself.

Proximity to sources of sediment and pollution: Unlike bryozoan biogenic habitats on the southern Australian continental shelf, the Western Port bryozoan reefs are in close proximity to industrial ports, a cruise ship anchoring zone, regional townships, agricultural lands and growing metropolitan populations centres. The reef area is already exposed to recognised sources of high terrigenous sediment input (Melbourne Water 2018), a situation that has emerged through changing land use practices and saltmarsh, mangrove and seagrass distributions in the north-northeastern sectors of the bay. The generally turbid nature of waters in East Arm likely plays a role in limiting competition by algae that may otherwise negatively impact bryozoan colony growth and survival. Our ground-truthing surveys have shown that tufts of fine red algae are present, but never dominant on the bryozoan mounds. Algae was identified as the main cause of bryozoan mortality in the Ligurian Bay reef (Cocito et al. 1998) and is the main competitor to hard corals on reefs (McCook et al. 2001). While many toxicants are considered low risk in Western Port (Melbourne Water 2018), herbicides, fungicides and insecticides are considered moderate risk, particularly close to creek mouths.

4. Recommendations for management and monitoring

This section relates only to recommendations as they relate to reef type and extent. Other recommendations associated with biodiversity, water quality etc., will be included in partner reports. In addition, recommendations related to the monitoring of reef type and extent are made in a partner report that addresses a citizen science recreational echosounder-based monitoring program.

4.1. Monitoring basis and endpoints

The Western Port bryozoan reefs are a newly discovered and described biotope and are therefore not identified as a significant habitat in the Ecological Character Description (ECD) of the Western Port Ramsar wetland (DELWP 2017). However, the concepts of habitat extent that are integral to the identification of Limits of Acceptable Change (LACs) to other ecological character descriptors (e.g. seagrass, mangrove and saltmarsh) of the area (DELWP 2017) apply equally to the bryozoan reefs. The Victorian Government is embarking on a process of identifying indicators of Good Environmental Status (GES), using the status descriptors of the European Union under the Marine Strategy Framework Directive as a starting guide (EC 2008).

As depicted in Figure 8, Good Environmental Status (GES) is central to establishing targets, selecting indicators and establishing monitoring objectives. GES is a quantitative or qualitative description of the condition/character of the environment that managers wish to maintain or drive towards improvement. The GES concept has been adopted by the European Union's Marine Strategy Framework Directive, which strives to achieve GES of the EU's marine waters by 2020. There are 11 GES descriptors (what the environment will look like when GES is achieved) (Marine Strategy Framework Directive, Annex I):

- Descriptor 1**.** Biodiversity is maintained
- Descriptor 2**.** Non-indigenous species do not adversely alter the ecosystem
- Descriptor 3**.** The population of commercial fish species is healthy
- Descriptor 4**.** Elements of food webs ensure long-term abundance and reproduction
- Descriptor 5**.** Eutrophication is minimised
- Descriptor 6**.** The sea floor integrity ensures functioning of the ecosystem
- Descriptor 7**.** Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
- Descriptor 8**.** Concentrations of contaminants give no effects
- Descriptor 9**.** Contaminants in seafood are below safe levels
- Descriptor 10**.** Marine litter does not cause harm
- Descriptor 11**.** Introduction of energy (including underwater noise) does not adversely affect the ecosystem

Each of these descriptors contains sub-criteria defined by various sources (e.g. Berg et al. 2015), such as:

- Descriptor D1. Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climate conditions.
    - Sub-criteria 1.1. Species distribution:

- 1.1.1 Species distribution range (extent).
- 1.1.2 Species distribution pattern within its range (i.e., fragmentation, patchiness or juxtaposition against other species/habitats is maintained).
- 1.1.3 Area covered by sessile benthic species.

These criteria are supported by evidence and linked to indictors (things to monitor to assess whether GES is achieved) and quantitative targets. Again, in the European context there has been a considerable body of work to define quantitative targets and many of these are translatable to Victoria with appropriate calibration and benchmarking against local policy and regimes of natural perturbations. GES definition therefore flows through to target-setting and selection of indicators that are closely tied to an objective, known (or hypothesised) ecological responses and particular triggers of a management response. With respect to bryozoan reef type and extent, the following GES indicators are recommended (the indicators underlined are those that require additional baseline data to adequately define):

- **Habitat distribution and extent**
  - No change in the overall distributional range of bryozoan linear and patch reefs.
  - No decline (beyond an error margin to-be-determined) in the extent of bryozoan reef biotope as derived from the semi-automated analysis of multibeam bathymetry used in this study or other suitable method.
- **Habitat composition, juxtaposition and fragmentation**
  - <u>No significant change in the composition and species dominance of the three reef-forming species.</u>
  - <u>No significant change in the spatial configuration of the reef-sediment-seagrass biotope mosaic at the mesoscale.</u>
  - No significant change in seabed integrity and geomorphology.
  - No fragmentation of linear reef.
- **Habitat condition**
  - <u>No increase in sedimentation between and on reef mounds.</u>
  - <u>No increase in the abundance of algae on reefs.</u>
  - No marine pest species on reefs.
  - No diseases affecting bryozoans introduced to the reefs.
  - <u>No significant change to zooid mortality, colony size,</u> matrix invertebrate fauna community composition and abundance<u>, epifaunal community composition and abundance and other indicators of reef health.</u>

4.2. Management actions

4.2.1. Formal conservation status

The Western Port Bryozoan Reefs Research Project is proceeding towards listing the bryozoan reefs under the Victorian Flora and Fauna Guarantee Act 1988 as a community that is prone to future threats that may lead to extinctions. If successful, the reefs will be one of only two other marine communities listed, the others being an intertidal reef near San Remo (Western Port) and the Port Phillip Entrance Canyon sponge communities. Other formal legislative conservation options available include listing the community on the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) List of Threatened Ecological Communities.

4.2.2. Recreational fishing monitoring and education

The Victorian Government is actively seeking to increase reactional fishing activity (Target 1 Million initiative) which may increase the pressure associated with physical damage from anchors and fishing lines. Recreational fishing activity should be monitored in terms of spatial intensity (has commenced as part of the Western Port Bryozoan Reefs Research Project and as per recommendation #4 of Ford and Gilmore (2013)) and linked to a program to monitor colony damage. Recreational fishers should be educated as to responsible anchoring practices. Precedence for this exists for the Port Phillip Bay shellfish reef restoration project, where fishers were educated about techniques to use current and wind conditions to maximise fishing on-reef while placing anchors off-reef.

4.2.3. Sediment management

Sedimentation and scouring are identified as potential threats to bryozoan reefs. Initiatives currently underway to decrease sediment inputs, rehabilitate mangrove and saltmarsh habitat, replant intertidal seagrass, replant riparian vegetation etc., while so far focussed on benefits to seagrass habitats, will also serve to protect bryozoan reefs. This study has identified the possible trapping of very fine sediment particles in the sediment tracts between linear reef rows. No data are available on sedimentation or turbidity at the bryozoan reefs, but previous studies identified Rhyll segment of East Arm as an area of fine sediments (Marsden et al. 1979) and depositional processes (Hancock et al. 2001) (Figure 20).

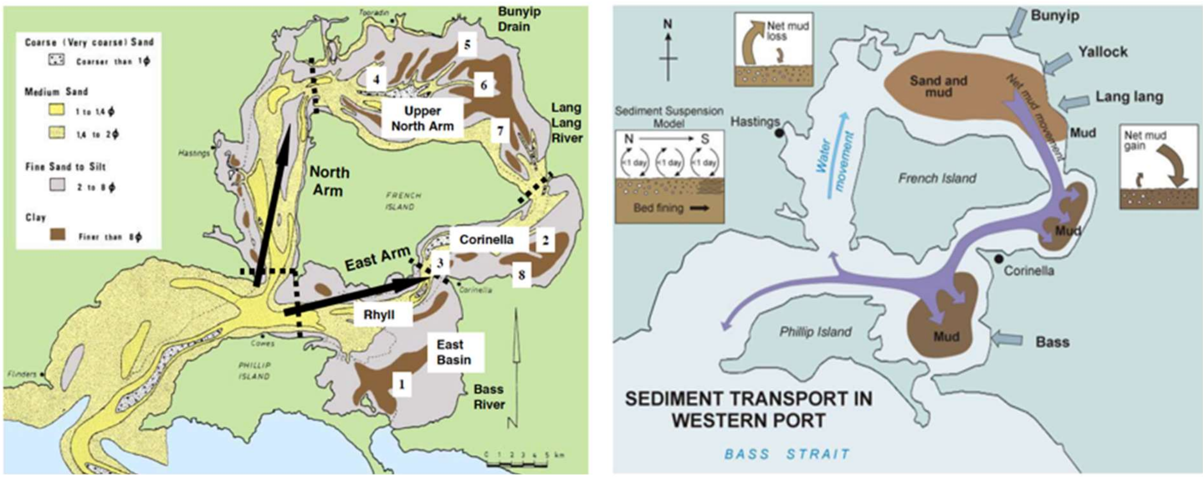


Figure 20 Sediment grain size distribution (top) and schematic illustration of transport processes (bottom). Approximate location of bryozoan reefs indicated by pink polygon. Source: Marsden et al. (1979) and Hancock et al. (2001).

Recent hydrodynamic models have shown the reef site is exposed to southerly transport of fine sediment particles via net water circulation from the northwestern sector of the bay (north of French Island), through the tidal divide and geomorphic constriction at Stockyard Point and into Rhyll segment of East Arm (Figure 21).

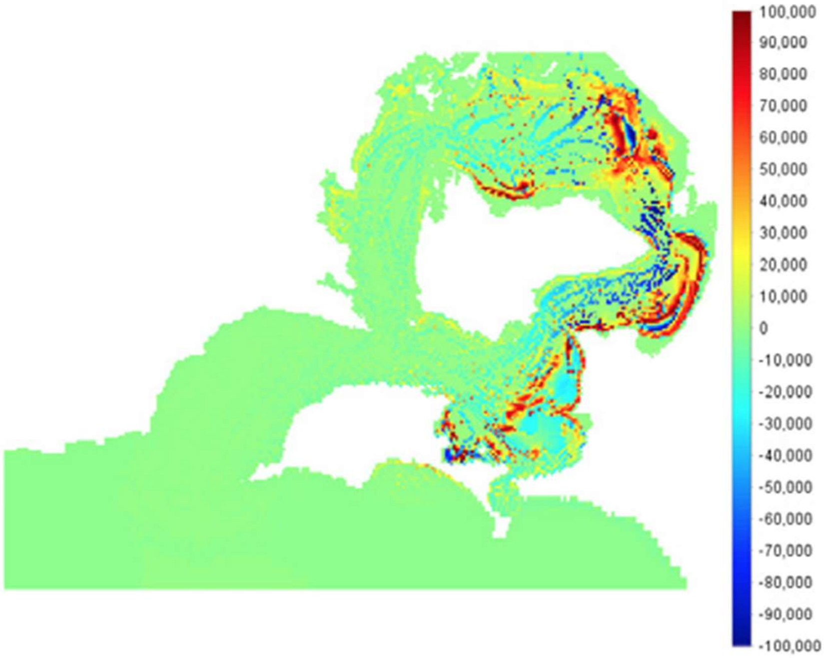


Figure 21 Modelled redistribution of fine bed sediment (<4 µm), 2004–2013. Units are g/m^2. Approximate location of bryozoan reefs indicated by pink polygon. Source: Melbourne Water (2018).

4.2.4. Marine pests

To date, very limited marine pest incursions have been reported in the Western Port region and there have been no major outbreaks in the bay. Wakame (*Undaria pinnatifida*) now prevalent throughout Port Phillip Bay, presents one of the highest direct risks to bryozoan reefs as the reefs represent the only significant solid substrate that may be colonised by algae. The Northern Pacific seastar (*Asterias amurensis*), also prevalent throughout Port Phillip Bay, presents a risk to the abundant bivalve community associated with the bryozoan reefs and a potential risk to bryozoans themselves.

Increasing industrialisation and growing needs for larger and more frequent commercial and passenger shipping operations in The Port of Hastings, in addition to increasing recreational vessel activity, increases the risk of potential marine pest introductions. Monitoring efforts should expand in step with this increasing risk, both at port locations and at highly sensitive locations.

4.2.5. Bryozoan reef partner studies and monitoring

Studies are underway that will further inform vulnerability and management recommendations and these will be described in partner reports. Age-and-growth studies, matrix and epifaunal invertebrate biodiversity and bioacoustic fish studies are among the relevant studies contributing to the project. Further research is required to develop a suitable baseline for some of the indicators identified in Section 4.1. The bryozoan reefs are a unique and remarkable addition to the knowledge of the ecological character of the Ramsar area. The present study, and partner studies of the Western Port Bryozoan Reef Research Project, has described key aspects of reef type and extent but as other results are brought together, more fundamental research will no doubt be required. As the site lays outside any protected area or commercial fishing grounds, a multi-agency, multi-stakeholder approach will likely be needed to continue the research.

5. Acknowledgements

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ATTACHMENT 1

Multibeam Survey Reports