

# Shellfish Reef Mapping in Subtropical Queensland

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Figure 1. *Saccostrea glomerata* (Sydney rock oyster) reefs at Sandstone Point, Queensland.

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## Project Summary

This project mapped the present and historical distribution of shellfish reefs across subtropical Queensland, including areas within the Moreton Bay and Great Sandy Marine Parks and the associated Great Sandy Strait and Moreton Bay Ramsar sites. The spatial products from this project included point maps (present and historical) as well as polygons (present only). A subset of present sites were characterised using an attribute-based approach and where possible, descriptions of historical reefs were documented for comparison with present sites. These characterisations and descriptions in conjunction with a series of expert workshops informed the development of shellfish habitat typologies under the Queensland Intertidal and Subtidal Classification Scheme. In total, 108 potential types were identified, however, further work is required to assess which of these types reflect actual shellfish habitat.

The mapping presented in this report provides an important first step in understanding where reefs currently occur and their present condition. Although shellfish habitats, populations of shellfish that do not meet 'reef' criteria, were included in mapping when located, a targeted search for these habitats was outside the scope of this project. This mapping therefore does not include all shellfish habitats in the region. Further work is also needed to improve mapping of subtidal shellfish habitats, which remain poorly understood. Critically, this includes developing an understanding of species capable of building reefs, as this report presents evidence that suggests that the Sydney rock oyster, *Saccostrea glomerata*, is an intertidal specialist. The current project provides a foundation, but not a complete picture, of shellfish reef extent and condition.

Overall, this project provides a baseline framework for mapping shellfish reefs and identifies the most critical gaps in knowledge whilst setting out clear directions for conservation and restoration. This project builds on the current National Environmental Science Program (NESP) project 4.13 "Assessing and mapping northern Australia's shellfish reefs". The information gained from mapping and characterising shellfish reefs in these projects provide a robust basis for shellfish reef management in Queensland, including within Marine Parks, Ramsar sites and World Heritage Areas, establish conservation needs, and inform listings under the Environment Protection and Biodiversity Conservation (EPBC) Act and Green Status of Ecosystems.

To aid future sampling efforts, we developed a rapid assessment tool to calculate minimum sample sizes to provide a less resource intensive approach to accurately characterise or monitor shellfish reefs. We then provided a path forward to enable future assessments using the Marine and Estuarine Condition Assessment Tool (MarECAT) framework, including how to develop an evidence-based scoring system for determining the condition of different types of shellfish reefs. Finally, we outlined key conservation needs in subtropical Queensland and provide recommendations for future research to fill critical knowledge gaps.

## Project Background

Shellfish reefs are biogenic structures created by dense aggregations of oysters and/or mussels and are usually located on unconsolidated or consolidated sediments. These ecosystems provide important services, including shoreline stabilisation, water filtration, nutrient assimilation, and the provision of habitat for marine life, including harvested fishes and crustaceans (Grabowski et al., 2012; zu Ermgassen et al., 2016). Destructive and unsustainable shellfish harvesting coupled with pollution, disease and coastal development have devastated shellfish reefs on the eastern and southern coasts of Australia, which are now critically endangered and considered functionally extinct (Beck et al., 2011; Gillies et al., 2018). There is a clear need to restore these ecosystems and their services. An important precursor to restoration is an understanding of the historic and current status of shellfish reefs in region specific areas to assess their specific conservation needs.

Subtropical Queensland represents a transitional zone between the tropics and subtropics and harbors multiple reef-building *Saccostrea* spp. (McDougall et al., 2024), along with other reef-building shellfish including hairy mussels, pearl oysters and leaf oysters (Diggles, 2015). Shellfish reefs in these warmer waters can function in different ways to temperate reefs. For example, tropical regions contain four times more reef-building oysters as temperate regions, and tropical species often have different spawning triggers, grow faster, and face unique environmental challenges (Richardson et al., 2022). It may therefore be inappropriate to base conservation decision-making for subtropical shellfish reefs on the ecology and conservation needs of their temperate counterparts. While a few existing subtropical shellfish communities have been classified and mapped in Intertidal and Subtidal Ecosystems Mapping for Central Queensland (DES, 2019), referred to as 'Central Queensland mapping', this project extends that work further south. Identifying the biophysical attributes associated with subtropical reef-building species provides a tool compatible with the scale and intent of management and addresses the current limited understanding of the current distribution, condition, and conservation needs of these habitats.

Native flat oyster (*Ostrea angasi*) reefs are currently being assessed under the EPBC Act. At the time of writing this report, a similar assessment was also underway for Sydney rock oyster (*Saccostrea glomerata*) reefs, however, this assessment was postponed due to data deficiencies surrounding the distribution, ecology and extent of *S. glomerata* reefs. These assessments do not include reefs formed by other species of shellfish such as hairy mussels, leaf oysters and pearl oysters, or the recently documented *Saccostrea* lineage B (McDougall et al., 2024; Richardson et al., 2025a). There is a need to develop a better understanding of the status (past and present distributions), and condition of different species of reef-building shellfish for future restoration and management.

## Project Aim

This project aimed to assess the status of shellfish reefs in subtropical Queensland. We created a historical map of shellfish reefs, adding to work done by Thurstan et al. 2020 by including the historical location of pearl oysters and leaf oysters identified through archived newspaper articles and museum specimens. We then mapped present shellfish reefs and included any shellfish habitats (non-reef areas where reef-building shellfish were abundant) such as small reef patches, encrusting oysters and isolated populations. This data is presented as both a present reef map (all shellfish reefs and habitats) and polygon layers (shellfish reefs only).

Several key sites were characterised using data on site characteristics, spatial attributes, live shellfish densities, species identification, and associated invertebrate communities. This attribute data, combined with a series of expert workshops, informed the development of shellfish habitat typologies under the Queensland Intertidal and Subtidal Classification Scheme (DEHP, 2017). We then developed a statistical approach to determine minimum sample sizes and indicator selection based on invertebrate data to inform future 'rapid assessments'.

To assess present reef condition (for *S. glomerata* only due to data availability), we compared measurements at current sites with measurements from historical sites. We supplemented this with present literature and a current Green Status of Ecosystems assessment for *S. glomerata* reefs and aligned this assessment with the draft Marine and Estuarine Condition Assessment Tool (MarECAT) (Cadier et al., 2024) to guide future condition scores, restoration and monitoring. While the assessments undertaken in this report are intended to aid in future decision-making and on-ground action, they are not intended for the sole use as a habitat suitability assessment.

## Historical Map

This component of the project aimed to reconstruct the historical distribution of shellfish reefs in subtropical Queensland to provide ecological context for present-day reef assessments. While previous efforts have compiled broad-scale historical accounts of likely oyster reef occurrences (Diggles, 2015; Thurstan et al., 2020), this work refines those records by georeferencing specific reef locations and translating them into spatial formats suitable for comparison with current distributions. These previous maps focussed on rock oysters, whereas in this map we have expanded the scope to include other species of reef-building shellfish, however, historical records for other reef-forming species remain limited. It is important to note that many of these records are based on descriptive accounts and may not precisely reflect historical reef locations. As such, they should be interpreted as indicative rather than definitive. A full list of coordinates and data sources are listed in Table S1 in Appendix B.

## Methods

To reconstruct a map of historical shellfish reefs, we collated data from a range of archival sources. This included data mining of primary literature such as Saville-Kent, 1891 and Smith, 1981, supplementary materials from Thurstan et al., 2020, museum specimens, and newspaper articles accessed via the Trove archive. Historical point locations were manually georeferenced where possible using satellite imagery (ESRI World Imagery, 15m resolution) within ArcGIS Pro (Esri) (Figure 2), however, in many instances this was not possible as the location was too broad (i.e., Moreton Bay). Each historical record was assigned a unique identifier based on species and tidal zone, and converted to spatial points object using the terra package in R. Visualisation of historical shellfish reefs were conducted in ArcGIS Pro, using IBRA7 national boundaries to delineate terrestrial and coastal features.

# Historical map

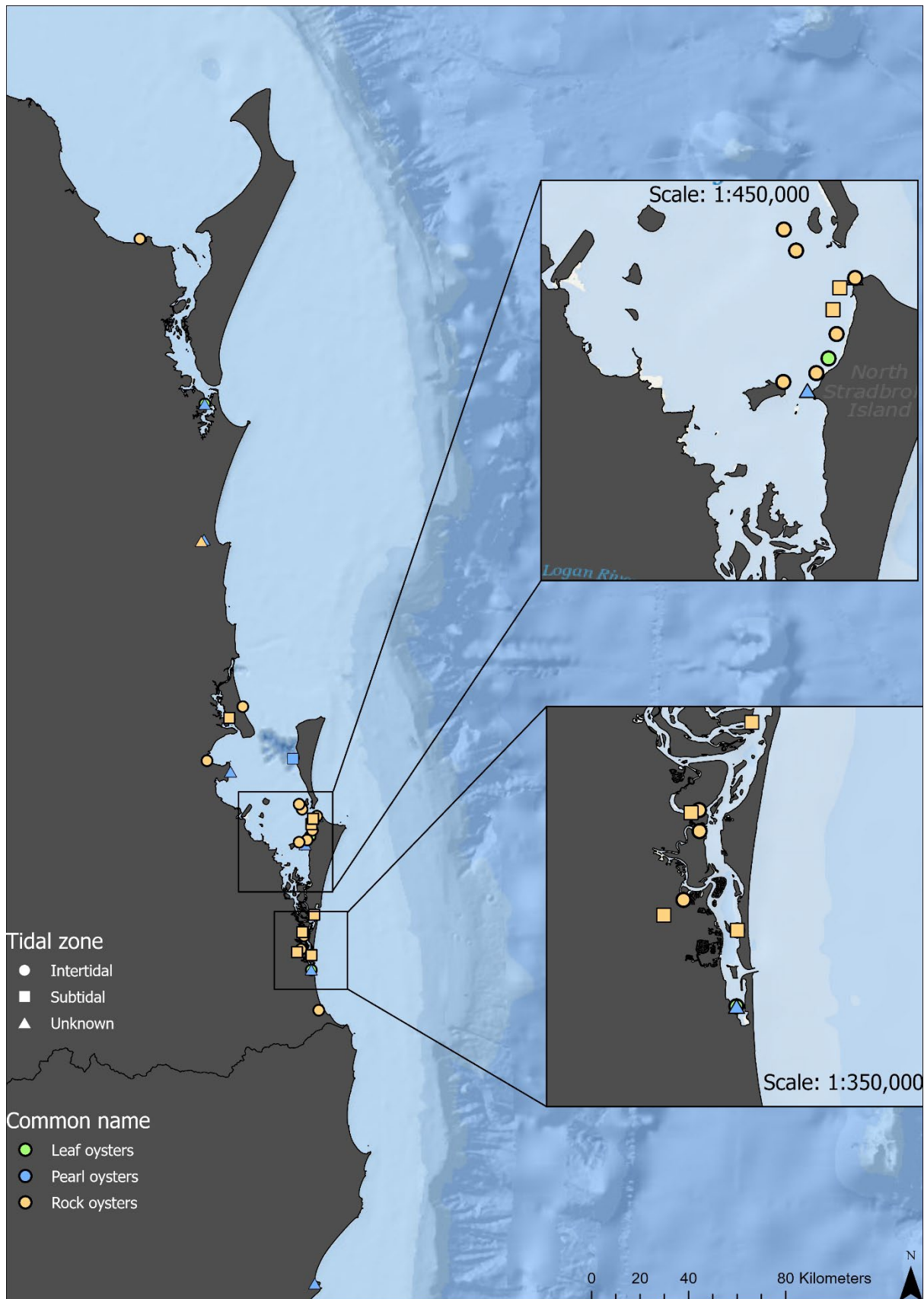


Figure 2. Historical distribution of shellfish reefs across subtropical Queensland. For full page inset maps, see Appendix A.

## Present Map

For the purpose of this map, we defined a shellfish reef as:

“An area consisting of one or more reef patches with at least 5 m<sup>2</sup> total coverage by live shellfish, and dominated by at least 25% live shellfish cover. Reefs growing on hard substrate must be > 2 shellfish thick. Shellfish communities ≤ 2 shellfish thick (a veneer), < 5 m<sup>2</sup> total coverage by live shellfish, and/or less than 25% live shellfish cover are not considered reefs”.

This definition was adapted from Gillies et al., 2018, zu Ermgassen et al., 2024 and NSW DPI, 2020, however, instead of at least one reef patch needing to be at least 5 m<sup>2</sup> we changed this definition to be the total sum of reef patches to be at least 5 m<sup>2</sup> to reflect the patchy nature of reefs in Queensland, both in the tropics (Richardson et al., 2025a) and in southern Queensland. These areas are termed “established reefs” in the present map (Figure 3), though this does not consider the condition of these reefs.

Although reefs were the focus of this project, we also included other shellfish habitats to aid in future suitability assessments and restoration. We defined these as being:

- Reef patches (too small in area to meet “shellfish reef” criteria).
- Encrusting oysters (less than 2 oysters in thickness, does not meet structural “shellfish reef” criteria).
- Isolated populations (too small in area and does not meet structural “shellfish reef” criteria).

Site photographs can be made available on request, while co-ordinates and other site information can be found in Appendix B.

## Methods

The location and distribution of intertidal shellfish reefs and habitats were identified primarily using satellite imagery, publicly available data (i.e., iNaturalist and Atlas of Living Australia) and collaboration with local stakeholders including government, OzFish and The Nature Conservancy. Subtidal shellfish habitats were identified through local site knowledge, collaboration with stakeholders and collaborators, and data mining existing subtidal seagrass surveys. Present-day reef point data was converted and mapped following the methods outlined for historical reefs for consistency.

## Present map

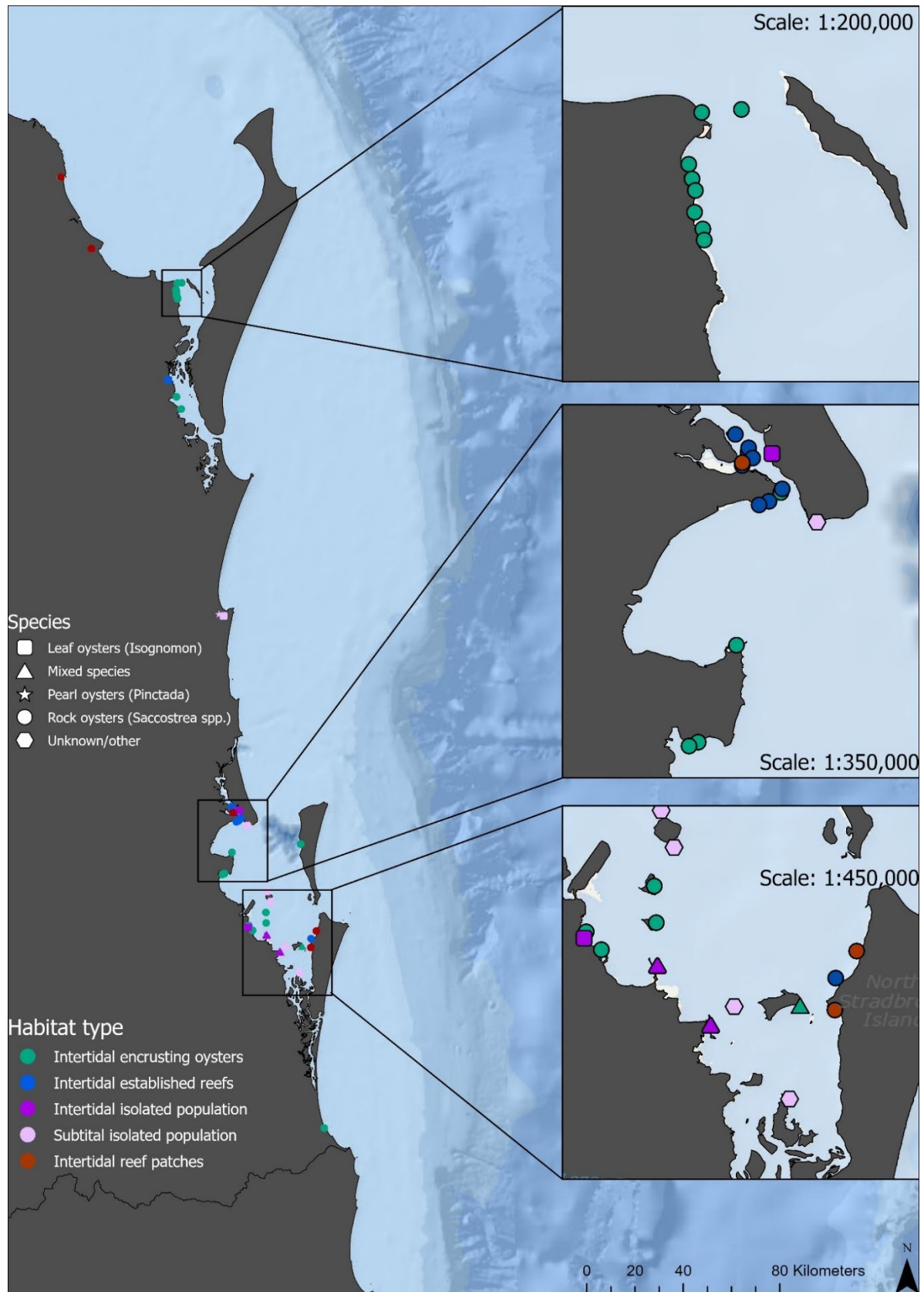


Figure 3. Present-day distribution of shellfish reefs across subtropical Queensland. For full page insets, see Appendix A.

# Shellfish Reef/Habitat Typology Methods

## Typology purpose

This typology was developed following the method outlined in the Queensland Intertidal and Subtidal Ecosystem Classification Scheme (DEHP, 2017), where identifying the typology purpose is a formal step (see section 5.2 in DEHP, 2017). It is designed to support rehabilitation needs and mapping efforts. While they will assist in validating future habitat suitability models, they are not predictive tools and do not account for condition or zoning purposes.

The specific purpose of the typology decided during workshops is to:

“Provide a consistent framework for mapping existing shellfish reef and habitat features in a way that is ecologically meaningful and spatially mappable. The typology reflects current habitat structure but does not incorporate factors that might explain the absence of shellfish. Such cases are considered matters of condition or missing data. While the typology may be used to validate habitat suitability models, it is not predictive. For subtidal reefs/habitats, an early structural split was introduced to keep classifications relatively simple due to data deficiencies. Although the primary focus remains on intertidal reefs/habitats, subtidal types are incorporated into the broader hierarchy and may be further developed as new data becomes available.”

## Attribute classifications

Attributes selected for the final typology were identified through group discussion, prioritising those that are ecologically meaningful and mappable. These include benthic depth, relative relief, consolidation, substrate composition, substrate grain size and structural macrobiota. Qualifiers such as biotic height and percent cover help to differentiate similar types, for example, high or low profile reefs, and which sites are shellfish “reefs” or shellfish “habitats” based on our definition. Attributes were collapsed into broad categories, and a hierarchical classification was applied, beginning with Terrain categories (benthic depth and relative relief), followed by Substrate categories (consolidation, substrate composition and substrate grain size), and finally structural macrobiota (Table 1). Typology methods are described in DEHP (2017) Section 5.2, and readers are referred to this document for all definitions associated with the classification and typology process (e.g., “attributes”, “qualifiers” etc).

Selected attributes and their categories were combined to create a hierarchical typology tree. Attributes were arranged in order so as to progressively split categories. For example, “tidal inundation” was the primary attribute used to distinguish intertidal habitats from subtidal habitats. Each subsequent attribute (e.g., relative relief, consolidation, substrate composition, substrate grain size and structural macrobiota) further divided the categories, creating distinct combinations that define habitat types. Table 1 presents the typology rulesets, where each row shows the diagnostic combination of attributes and categories (“x”) that classify a particular type. Not all attributes participate in every ruleset, reflecting the ecological variability and data

availability across sites.

## Typology outputs

While intertidal reefs/habitats formed the majority of types, subtidal types will be integrated as more data is collected. The typology was expected to describe approximately 50 habitat types; however, combinations of attributes resulted in 108 distinct types. It should be noted that some of these types may not actually exist, and further characterisations are required to ground-truth shellfish reef/habitat types. Over time as more data is collected, this typology may benefit from fine-tuning to remove redundant types, splitting subtidal and intertidal shellfish reef/habitats into two typologies (if deemed necessary), or further collapsing categories to reduce the overall number of types. Methods for collapsing categories are outlined in DEHP, 2017.



THEME		TERRAIN						SUBSTRATE											BIOTA																				
Attribute	Benthic depth		Relative relief				Consolidation			Substrate composition				Substrate grain size (folk)							Structural macrobiota																		
Category	>0m (above AHD)	0m to 5m	5m to 10m	>10m	Very low	Low	Medium	High	Very high	Consolidated	Intermediate	Unconsolidated	Tenigenous	Other or unspecified	Calcareous - Biogenic - shell	Calcareous - Biogenic - coral	Calcareous - Biogenic -	Sandy GRAVEL	Gravelly SAND	Gravelly muddy SAND	(Slightly gravelly) SAND	(Slightly gravelly) muddy SAND	Muddy GRAVEL	Gravelly MUD	(Slightly gravelly) sandy MUD	BOULDER	GRAVEL	Mollusc - shellfish (mixed or other)	Mollusc - rock oysters	Mollusc - leaf oysters	Mollusc - pearl oysters	Mollusc - mussels	Mollusc - invasive shellfish						
Collapsed	Intertidal	Subtidal		Veneer (encrusting oysters on consolidated substrate only)			Low profile (<15 cm)		High (15cm and greater)		Consolidated	Intermediate	Unconsolidated	Tenigenous/other	Calcareous - Biogenic Shell	Calcareous - Biogenic Other	Soft sediment and gravel							Boulder and gravel	Soft sediment, boulder and gravel		Mollusc - shellfish (mixed or other)	Mollusc - rock oysters	Mollusc - leaf oysters	Mollusc - pearl oysters	Mollusc - mussels	Mollusc - invasive shellfish							
Type 73	x						x			x			x																x										
Type 74	x						x			x			x																	x									
Type 75	x						x			x			x																							x			
Type 76	x						x					x	x								x																		
Type 77	x						x					x	x								x																		
Type 78	x						x					x	x								x																		
Type 79	x						x					x	x														x										x		
Type 80	x						x					x	x														x												
Type 81	x						x					x	x														x										x		
Type 82	x						x					x	x																										
Type 83	x						x					x	x																										
Type 84	x						x					x	x																										
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Type 106		x					x			x																													
Type 107		x					x					x																											
Type 108		x					x					x																											

## Polygons and Shellfish Reef/Habitat Types

Polygons were generated for all shellfish reefs, and shellfish habitats identified as “reef patches” and “high-density encrusting oysters”, while shellfish habitats identified as “low-density encrusting oysters” and “isolated populations” were excluded (see Appendix B, Table S2). Sites where polygons were generated included Elliott Heads, Walkers Point, Booral, Maaroom, Myora north, Myora south, Dunwich, Pumicestone Passage (6 sites), Toorbul Point (2 sites), Sandstone Point (2 sites), and Tallebudgera Creek. Most sites were comprised of multiple patches within the same shellfish reef or habitat, and were therefore represented by multiple polygons.

### Methods

Each polygon was assigned attributes informed by the typology exercise during workshops, including benthic depth, relative relief, consolidation, substrate composition, substrate grain size, and structural macrobiota. Additional information in the attribute tables include qualifiers to delineate shellfish reefs from shellfish habitats per our definition; the percent cover qualifier has a threshold of 25% live shellfish cover, while biotic height qualifier has a threshold of 2 oysters in thickness for rock-based reefs/habitats only (there is no minimum height for soft sediment reefs). Polygon area, reef shape (patchy or continuous) as defined and described in the Queensland Intertidal and Subtidal Ecosystem Classification Scheme (QISECS) (Appendix 6.5) (DEHP, 2017), and primary settlement substrate (rock or shelly sediment; note that these are a typology of substrate consolidation and substrate composition which are attributes of the QISECS (DEHP, 2017)) were also included to stay consistent with terminology used in similar mapping projects and existing literature (NSW DPI, 2020; Richardson et al., 2025a). “Reef footprint” (the total area of shellfish reef only within polygons) will be added as an attribute once remaining sites have been determined by drone assessment, and will be used as an additional qualifier to delineate shellfish reefs from habitats as per our definition. Additional spatial data derived from drone mapping will also be included once they have been collected, such as terrain morphology, site slope, site aspect, inundation, and more accurate measures of percent cover. Where data was incomplete or uncertain, fields were marked as unknown to maintain transparency and to highlight future data collection needs. Polygons were created in ArcPro V3.5.0 by manual interpretation using ESRI world satellite imagery at a scale of 1:500 for all locations except Myora South which was an interpretation of high-resolution drone footage at a scale of 1:250. Individual polygons were merged to make a single multi-polygon for each location (Figure 4). Area was calculated using the geometry calculator tool in ArcPro and the polygon vector was merged with the attribute table in R.

## Habitat types

Across the mapped sites, five types were identified from 15 sites able to be given a typology. The most common types were Type 92 (n = 5): “Intertidal, high profile, unconsolidated, calcareous biogenic shell, soft sediment, boulder and gravel rock oyster habitats” and Type 86 (n = 5): “Intertidal, high profile, unconsolidated, calcareous biogenic shell, soft sediment and gravel rock oyster habitats” (see Table 2 for details). These typologies provide an initial foundation for understanding the variation in shellfish reefs/habitats across subtropical Queensland. Further characterisations are required to identify potentially redundant types and to fine-tune typologies.



Figure 4. Polygons of the four different types classified for rock oyster habitats. Panel A shows oyster reefs in Pumicestone Passage (sites 1 – 3, Type 86); Panel B shows oyster habitats in Booral (Type 2); Panel C shows oyster reefs in Myora South (Type 35); and Panel D shows oyster reefs in Sandstone Point (sites 1 and 2, Type 92). See Table 1 for typology attributes.

Table 2. Assigned typology types for each mapped reef site based on attribute combinations.

LOCATION	BENTHIC DEPTH	RELATIVE RELIEF	CONSOLIDATION	SUBSTRATE COMPOSITION	SUBSTRATE GRAIN SIZE	STRUCTURAL MACROBIOTA	TYPE
<b>Elliot Heads</b>	Intertidal	High profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment, boulder and gravel	Mollusc - rock oysters	Type 92
<b>Booral</b>	Intertidal	Veneer	Consolidated	Calcareous – Biogenic Shell	Soft sediment, boulder and gravel	Mollusc - rock oysters	Type 2
<b>Maaroom</b>	Intertidal	Low profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment and gravel	Mollusc - leaf oysters	Type 36
<b>Myora north</b>	Intertidal	Low profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment and gravel	Mollusc - rock oysters	Type 35
<b>Myora south</b>	Intertidal	Low profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment and gravel	Mollusc - rock oysters	Type 35
<b>Pumicestone Passage 1</b>	Intertidal	High profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment and gravel	Mollusc - rock oysters	Type 86
<b>Pumicestone Passage 2</b>	Intertidal	High profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment and gravel	Mollusc - rock oysters	Type 86
<b>Pumicestone Passage 3</b>	Intertidal	High profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment and gravel	Mollusc - rock oysters	Type 86
<b>Pumicestone Passage 4</b>	Intertidal	High profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment and gravel	Mollusc - rock oysters	Type 86
<b>Pumicestone Passage 5</b>	Intertidal	High profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment, boulder and gravel	Mollusc - rock oysters	Type 92
<b>Pumicestone Passage 6</b>	Intertidal	High profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment and gravel	Mollusc - rock oysters	Type 86
<b>Sandstone Point 1</b>	Intertidal	High profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment, boulder and gravel	Mollusc - rock oysters	Type 92
<b>Sandstone Point 2</b>	Intertidal	High profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment, boulder and gravel	Mollusc - rock oysters	Type 92
<b>Toorbul Point 1</b>	Intertidal	High profile	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment, boulder and gravel	Mollusc - rock oysters	Type 92
<b>Tallebudgera</b>	Intertidal	Veneer	Unconsolidated	Calcareous – Biogenic Shell	Soft sediment, boulder and gravel	Mollusc - rock oysters	Type 2

\*Note that a typology type was not able to be given to sites Walkers Point, Dunwich or Toorbul Point 2 due to limited attribute data.

## Locating Subtidal Shellfish Reefs in Moreton Bay

To investigate the current distribution of subtidal shellfish reefs, substrate were surveyed throughout a 10km section of Pumicestone Passage (26.9394°S, 153.0698°E) (Figure 5). This particular location provides insight into the abiotic and biotic habitat features ranging from bare sand to large reef structures and are located within management zones of the Moreton Bay Marine Park.

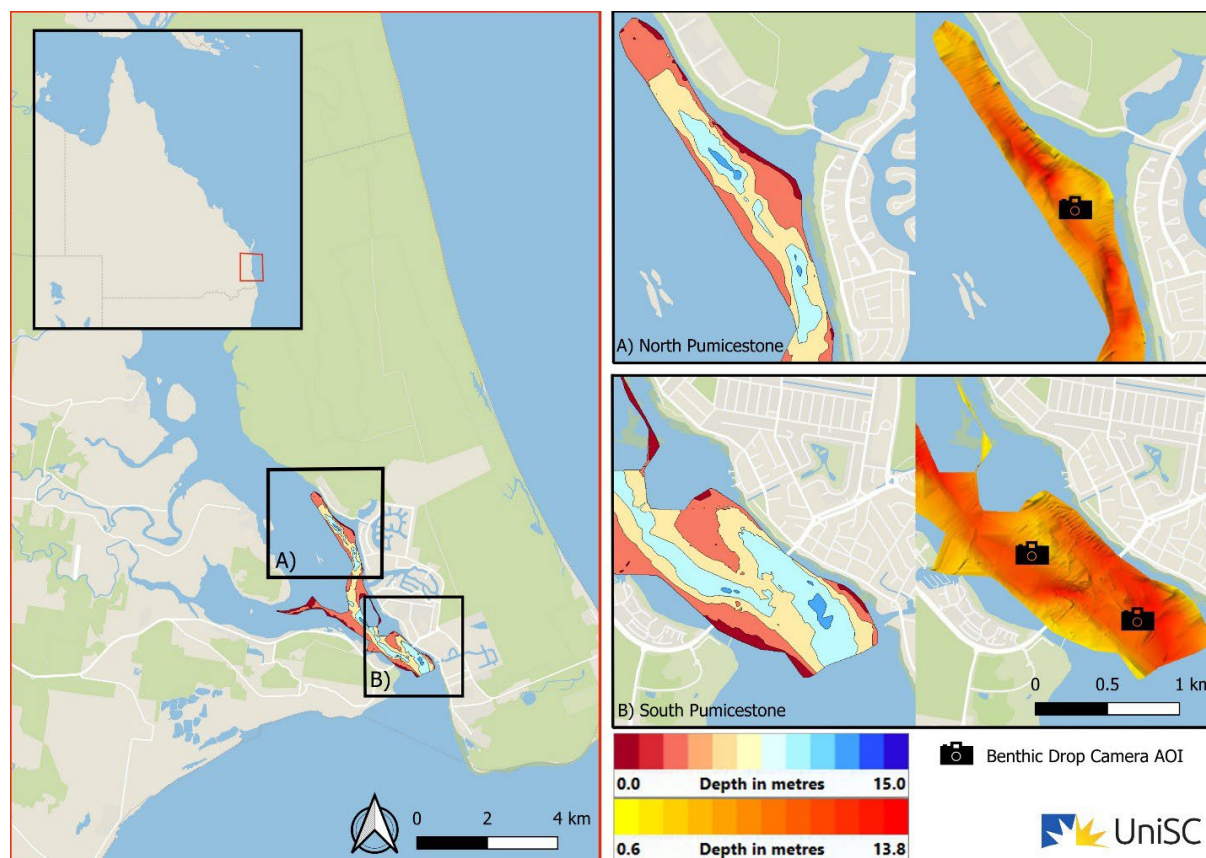


Figure 5. Location of general study area (left), Pumicestone Passage, South-East Queensland, Australia (inset). Bathymetry data displayed (right) using isobaths (changing depth, red to blue) and 3D shaded relief (changing depth, yellow to red). Indicates areas of interest for benthic drop camera surveys (shown with camera icon).

### Mapping bathymetry and quantifying terrain variation

To assist the search for subtidal shellfish reefs, we will create high-resolution ( $= 1\text{m}^{-1}$ ) Digital Bathymetry Models (DBMs) throughout the Pumicestone Passage using sonar data collected with an acoustic sounder (Lowrance HDS7 – Gen3). Bathymetric and backscatter maps throughout the channel were created by logging the bathymetry variation on overlapping longitudinal and latitudinal transects, without exceeding a maximum speed of 8 km/h. Sonar data is processed in ReefMaster 2.0 and corrected to the highest astronomical tide (HAT) using data collected from the nearest tidal station (The Skids, Pumicestone Passage, ID: 12345).

## Quantifying habitat composition

Surveys of habitat cover, and composition were completed on each survey event using drop-cameras. Drop-cameras and frames were comprised of a high-definition GoPro 10 mounted on a steel frame that creates a 50cm x 50cm quadrat over the desired benthos. Drop-cameras were deployed at sites of reef structure along the 10km channel transect. The mean cover of shellfish, hard coral, soft coral, algae and bare sediment at each reef location were calculated from reviewing the drop-camera video footage.

## Preliminary findings

Subtidal shellfish reefs continue to be significantly overlooked by global habitat mapping projects, due to high costs of equipment and time, as well as technological limitations (Caretti et al., 2021). Throughout the early months of 2025, a University of the Sunshine Coast (UniSC) project team, led by Associate Professor Ben Gilby and PhD candidate Edward Hay, commenced collecting and processing bathymetry data resulting in the first high-resolution ( $= 1\text{m}^{-1}$ ) Digital Bathymetry Models (DBMs) throughout the Pumicestone Passage (26.9394°S, 153.0698°E) using sonar data collected with an acoustic sounder (Lowrance HDS7 – Gen3). As can be seen in Figure 5, we have established locations throughout Southern Pumicestone Passage displaying significant changes in depths and sloping edges. Approximately 5 sites of interest have deep holes ranging from 12-15m, and a northernmost area of interest where shallow areas (approx.  $<0.5\text{m}$ ) quickly plunge to significant estuary depths (approx.  $>12\text{m}$ ).

Finding unique areas and physical characteristics in bathymetry surveys is the first step to uncovering the remaining distribution of Moreton Bay's subtidal shellfish reefs. From these DBMs, we will obtain measures of depth, hardness, roughness and slope to locate areas of interest and potential subtidal shellfish reefs. Well-known characteristics of shellfish reefs, such as encrusting rigid settlements along hard surfaces, give opportunity to use underwater bathymetry as key indicators of entirely unknown reef locations. Thus, seafloor complexity metrics (hardness, roughness and slope) and seafloor relief (depth) will be used as key indicators of remaining subtidal shellfish reefs and other significant 3D structures (Borland et al., 2021). Understanding subtidal shellfish reef distribution using predictive modelling, will be strengthened using statistical analysis, where we will look to establish potential significant relationships between bathymetry metrics and locations of structure. Percentages of composition will be recorded from underwater footage including (but not limited to) shellfish, hard coral, soft coral, algae and bare sediment. We will survey areas ranging from control (random) sites with limited structure (e.g., sandflats and randomised points), bare structures (e.g., coffee rock) and areas of interest (e.g., reef and encrusted structure).

Bathymetric data allows us to begin uncovering the locations and characteristics of

an unknown, yet critically important habitat-forming subtidal shellfish species. This search for Moreton Bay's subtidal shellfish reefs highlights potential for national expansion and industry collaboration, as well as providing the unique opportunity for large-scale search habitat mapping. Further to this, establishing reliable and consistent ground-truthing will be key in all future subtidal reef mapping on a national level (along with many other hard structure habitats). Our preliminary findings have established the possibility of locating, mapping and describing the extent of subtidal shellfish habitat throughout the Moreton Bay Marine Park. Understanding the distribution and physical characteristics of subtidal shellfish reefs and other hard structure habitat is critical for informing conservation strategies, restoration potential and guiding efforts to re-establish foundational habitats.

## Reef Condition

### Historical reef reference state and present condition

To create an understanding of the historical condition of shellfish reefs in subtropical Queensland, we compiled accounts describing the structure and size of reefs at specific locations. This work aimed to provide a baseline for current reef condition for rock oyster reefs (*Saccostrea* spp.) only, as other species of reef-building shellfish are historically data deficient. Historical information was sourced through supplementary material from Thurstan et al., 2020, Saville-Kent, 1891 and newspaper articles through the Trove archive which provided insights into the physical characteristics of historical shellfish reefs. Descriptions from archival materials indicate that oyster reefs were historically extensive and occurred across a broad range of substrates (Table 4). For example, Saville-Kent, 1891 noted that “reefs in their most characteristic state rest simply on clay or gravel basis but are not unfrequently associated with a rocky outcrop as their starting point.” Similarly, oyster reefs in the Gladstone region were reported to consist of “gravel and coarse sand overlaying a tenacious clay,” and oysters were often attached to stones, dead shell, or living whelks. Other accounts, such as those from Skirmish Point, Elimbah Creek, and Pumicestone Passage, describe large oyster beds associated with mudflats, mangrove islands, and soft sediments.

In contrast with descriptions of historical reefs, our current mapping has found that rock oysters have potentially shifted from occurring on soft sediments to predominantly overlaying rocky substrates. Of the 38 rock oyster reefs and habitats we located in this study, only 7 were found to be growing exclusively in soft sediment, 30 were growing on rock, and one site was a combination of rock and soft sediment. This potentially indicates a greater loss of soft-sediment reefs vs rock-based reefs, and highlights that some shellfish reef/habitat types may be more threatened than others.

In terms of present condition, the reefs we characterised exhibited clear signs of structural decline relative to historical baselines, with many reefs displaying low vertical relief, and patchy distributions of live oysters. This was most noticeable at sites in Pumicestone Passage where there was also a large amount of dead shell, and following Cyclone Alfred (which occurred after these reefs were characterised) there was evidence of further deterioration. There is a need for ongoing monitoring of these reefs to establish longer term series of data where reef condition can be linked with natural variation, or patterns of ongoing recovery or decline. Current reefs are functioning at a reduced capacity and unlikely to resemble their historical state without intervention. However, it is difficult to estimate precise declines in condition given that historical accounts are largely descriptive, and there is variation among the types of structures that rock oysters build. For example, reefs in Myora were much lower in profile compared to other sites, but contained high numbers and percent cover of live shellfish. The structural difference between Myora and other sites may

therefore be a natural variation rather than evidence of degradation. This warrants further investigation. Regardless, it is still clear from literature that rock oyster reefs have disappeared from most of their former range and are in need of restoration (Gillies et al., 2015, p. 201, 2018; McLeod et al., 2019). The lack of historical information for other reef-building shellfish species such as leaf oysters, pearl oysters and hairy mussels also underscores the need for further investigation. Alternative methods to provide accurate baselines, such as locating and characterising “healthy” remnant reefs that could act as proxies in regions outside of subtropical Queensland may be necessary.

Understanding the current condition of these reefs is challenging because they represent different ecosystem types, making direct comparisons difficult. For example, Pumicestone Passage reefs could be considered in better condition due to higher structural relief and evidence of recent recruitment, whereas Myora South might be assessed more favourably on the basis of higher percent cover and a diverse invertebrate community. Both perspectives are valid, but they highlight that reef “condition” depends on the metrics chosen. Similarly, characterisation of *Saccostrea* reefs in tropical Queensland showed that reefs with both the lowest oyster counts and vertical height contained the most abundant invertebrate communities (Richardson et al., 2025a). Overall, present reefs can be considered to be in reasonable condition given that they continue to support functioning invertebrate assemblages and have persisted despite ongoing threats, however, there have clearly been substantial long-term declines compared to historical baselines.

Table 4. Historical descriptions of reef locations, structure, and size in subtropical Queensland.

Location	Primary settlement substrate	Relative relief	Source
<b>Moreton Bay</b>			
Pumicestone Passage	Not specified	1m thick and 250-300 m long	Lergessner (2006)
Bribie Passage	Noteworthy that oysters are on ironstone pebbles (less common).	Not specified	Saville-Kent (1891)
Moreton and Wide Bays to Rodd Harbour	Most characteristic state rest simply on a clay or gravel basis, sometimes starting from rocky outcrops.	>1 m thick; upper crust of living oysters 13-30 cm	Saville-Kent (1891)
Moreton Bay	Not specified	Over 1.6 km long	The Queenslander, 8 Sep 1906
Moreton Bay	Not specified	Available banks >4,000 ha	The Queenslander, 8 Sep 1906
<b>Central Queensland</b>			
The Narrows	Layers of old oyster shells were up to 1.2 m thick, and calcareous rocky reefs rose 1.5 m above the water.	800-900 m long, 1.2 m thick (shell), 1.5m thick (rock).	The Capricornian 15 Mar 1924
The Narrows	Substratum of gravel, coarse sand, and clay with larger pebbles.	1-1.5 m thick	Saville-Kent (1891)
The Narrows	Not specified	>200 m long, 1.2-1.8 m thick	The Capricornian 15 Mar 1924
Rocky Bay (North End)	Jutting rocks and caves with oyster-laden beds.	Not specified	Morning Bulletin Rockhampton, 27 Oct 1936
Cape Upstart	Not specified	1.2 km long	Morning Post Cairns, 17 May 1904

Table 5. Present reef structure and estimated decline in condition compared to historical baselines.

Site	Primary settlement substrate <sup>1</sup>	Relative relief <sup>2</sup>	Decline <sup>3</sup>
<b>Myora South</b>	Shelly sediment	7-14cm	Up to 86%*
<b>Pumicestone Passage 1</b>	Shelly sediment and rock	15 - 39cm	61%
<b>Pumicestone Passage 2</b>	Shelly sediment	14 - 36cm	64%
<b>Pumicestone Passage 3</b>	Shelly sediment	18 - 58cm	52%
<b>Pumicestone Passage 4</b>	Shelly sediment	24 - 36cm	64%
<b>Sandstone Point 1</b>	Rock	15 - 39cm	61%
<b>Sandstone Point 2</b>	Rock	9 - 31cm	69%

<sup>1</sup> Recorded through field assessments.

<sup>2</sup> Estimated using conservative assumptions based on 1m historical reef thickness.

\* Important to note that this reef may naturally have been lower in profile than Pumicestone Passage reefs, and therefore less degraded.

## *Saccostrea glomerata* – an intertidal specialist?

Recent research, including information generated in this report, has provided strong evidence that *S. glomerata* is likely an intertidal species which was historically misidentified subtidally (Richardson et al., 2026). Although there is evidence of subtidal reefs as deep as 8 – 10m, it has been presumed that the reef-species was *S. glomerata*, however, no subtidal adults have ever been unambiguously identified through DNA. In the Noosa River estuary, although *S. glomerata* recruited subtidally (1 - 2m below the low water mark), spat mortality was high and no adults were present at any sites, and the highest numbers of both adults and spat were actually observed in the upper intertidal zone (Richardson et al., 2025b).

If *S. glomerata* were truly capable of forming subtidal reefs, it is difficult to reconcile why no subtidal populations have re-established, particularly given the abundant supply of spat observed across Queensland and New South Wales (O’Hare et al., 2021). Suggested causes of the inability for *S. glomerata* reefs to re-establish subtidally include sedimentation, competition with turf algae, declining water quality, and biotic pressures such as mudworm infestations and disease, all of which have been documented throughout Queensland estuaries (Ogburn et al., 2007; Diggles, 2013; Raftos et al., 2014). However, the inability for any subtidal populations of *S. glomerata* to return anywhere would imply a widespread decline in water quality across the entire east coast of Australia to the point that no locations remain suitable. More plausibly, we suggest that historical subtidal reefs were formed by multiple species of shellfish which have likely been unable to re-populate due to a collapse in larval supply from intense over-harvesting.

Potential candidates for subtidal oysters previously assumed to be *S. glomerata* include *Magallana dactylena*, with the earliest specimens dredged from the mouth of the Brisbane River in 1921 from a depth more closely matching historical accounts of 8 – 10m (Gillies et al., 2018). More recently, shell specimens washed ashore (likely from subtidal areas) have been found at Red Beach, Bribie Island in 1995 (Figure 9), as well as several tropical beaches near Proserpine in 2024 (Richardson et al., 2026), strongly indicating that this species still persists to the present day. Historical sketches by (Saville-Kent, 1891) (Figure 10) depict what was presumed to be the intertidal form of *S. glomerata* (sketch 1) and the subtidal form of *S. glomerata* (sketches 4 and 5). The morphology illustrated in the subtidal form more closely resembles *M. dactylena*, which we believe has been historically misidentified as *S. glomerata* in southern Queensland.

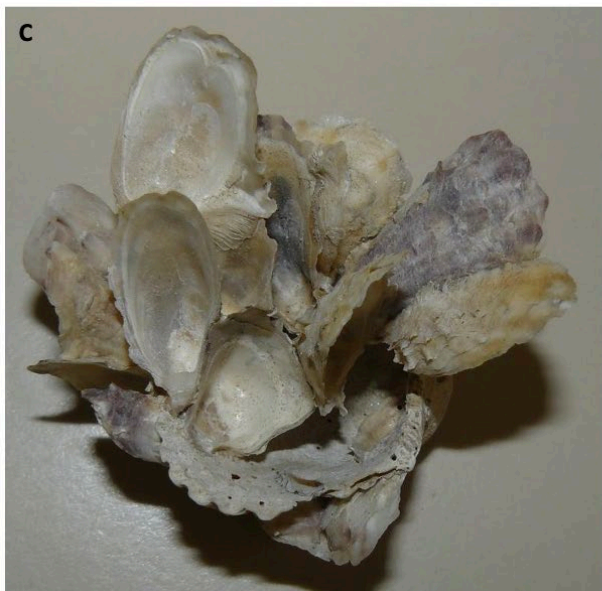


Figure 9. *Magallana dactylena* specimens from the Queensland Museum. Panel A and C represent specimens dredged from the mouth of the Brisbane River in 1929 while Panel B and D represent specimens collected from Red Beach, Bribie Island in 1995.



Figure 10. Historical sketches by Seville-Kent (1891) depicting presumed forms of *S. glomerata*. Sketch 1 shows the intertidal form, while sketches 4 and 5 illustrate the subtidal form, noting that the subtidal form was much paler in colour compared to the intertidal form.

In addition to *M. dactylena*, it is likely that other species of oysters were also subtidal reef-builders as can be inferred from a subtidal oyster clump collected near Mud Island in Moreton Bay at a depth of 8 – 10m (Figure 11). From similar looking specimens in the Queensland museum and specimens identified using DNA by McDougall et al., 2024, these oysters appear to belong to the genus *Hyotissa*, *Spondylus* and unknown species, however, it is impossible to be sure without further molecular work. It is also possible that even more species were presumed to be *S. glomerata* in subtidal environments. Given that the disappearance of subtidal shellfish reefs was largely due to dredging for the lime-burning industry (Gillies et al., 2015), early dredgers may not have paid close attention to shell morphology, so long as dredged material was suitable for quick-lime production. It is possible that *S.*

*glomerata* is restricted to intertidal habitats, however, the species has still undergone severe historical declines (Gillies et al., 2018), and is in need of restoration. For management, this means that restoration and conservation of *S. glomerata* should currently focus on intertidal habitats, where it is most viable. Until subtidal reef-forming species are unambiguously identified, attempting restoration in this habitat would be high risk and potentially ineffective. To address this uncertainty, molecular work needs to be undertaken. A targeted survey of subtidal oyster populations is required to determine which species are reef-building and to achieve unambiguous identifications through genetic testing (Richardson et al., 2026). Without this, it is not possible to determine which species historically built subtidal reefs, nor can we set reliable priorities for their conservation or restoration.

Improving our taxonomic knowledge of reef-building subtidal oysters through genetic and morphological analyses remains a key priority to manage shellfish reefs ecosystems across the eastern coast of Australia, including subtropical Queensland. This urgently needs to be addressed, as any existing subtidal species not yet extinct will almost certainly be in even greater need of protection and restoration than intertidal shellfish reefs.



Figure 11. Subtidal oysters consolidated into a single reef clump collected from 8 – 10m of water near Mud Island, Moreton Bay. The primary settlement substrate appears to be coral rubble.

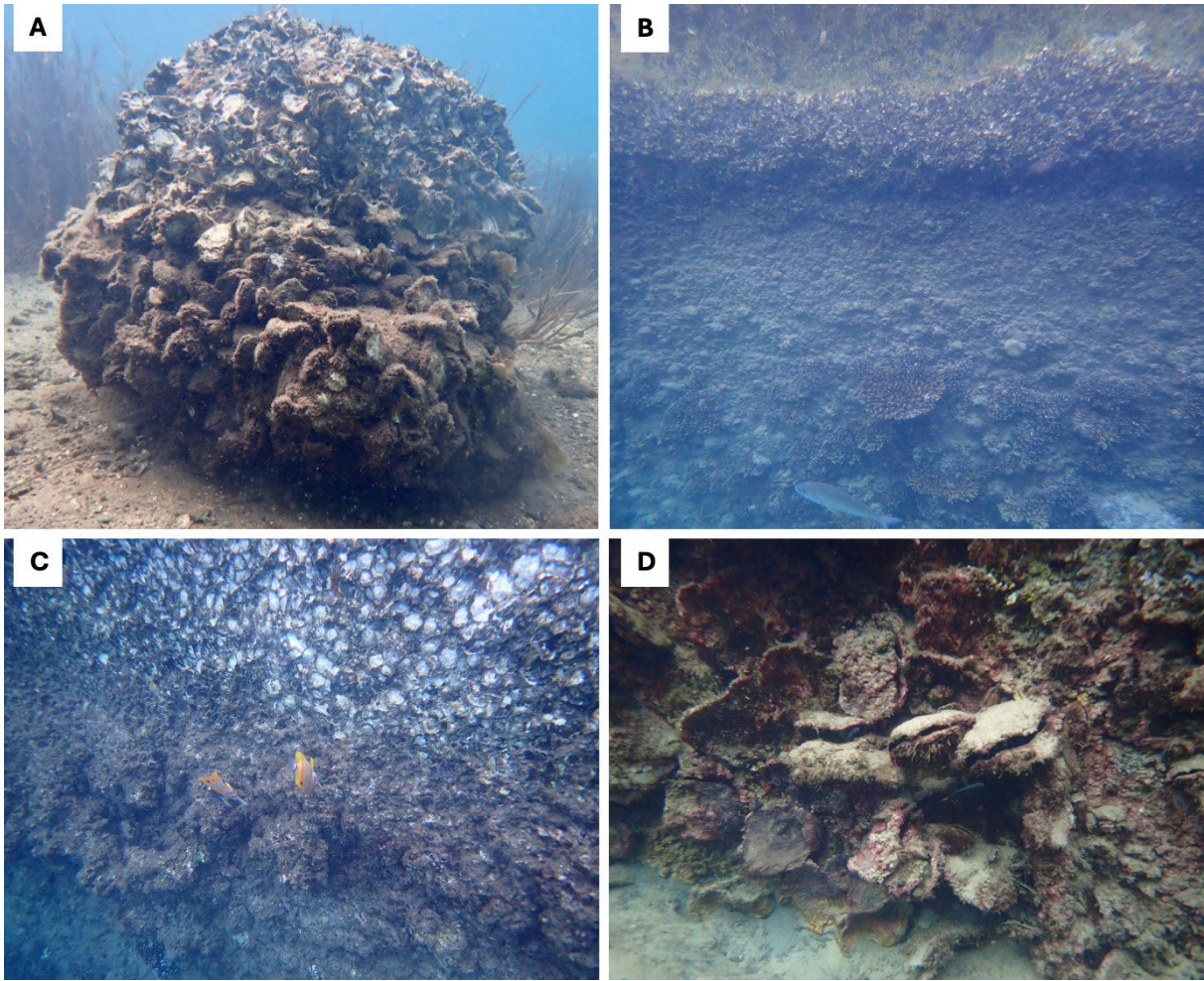


Figure 12. Panel A shows an intertidal shellfish reef in Korogoro Creek, central NSW about 200m from the creek mouth which flows directly into the Pacific Ocean. Clear zonation can be seen between *Saccostrea glomerata* (top) and a different species of bivalve (bottom). Panels B and C are examples of oyster species zonation on the Tangalooma wrecks, QLD. Rock oysters can be seen in the intertidal zone at the top of bands while other shellfish species occur in the lower bands. Panel D shows subtidal oysters (which do not appear to be *S. glomerata*) occurring subtidally on the same wrecks.

## Macroinvertebrate communities

As part of our reef characterisations, we collected invertebrates from oyster reefs at Sandstone Point, Pumicestone Passage, and Myora south to quantify community assemblages. Rather than using a taxonomic approach, we used functional groups to gain an understanding of the service provision and overall function of reefs. As part of this dataset, we also included previously collected data (using the same methods) from Gladstone, Proserpine and Mapoon to investigate whether subtropical sites were different to tropical sites. Over time as more reefs are characterised, this will help to determine suitable reefs outside of subtropical Queensland that could act as suitable baselines for restoration and monitoring.

The invertebrate community composition varied notably between upper and lower intertidal zones across all sites except for Mapoon and Proserpine which were the two most northern sites (Figure 13). For Gladstone and all subtropical sites, the upper intertidal zone was generally dominated by grazers, while the lower intertidal zone was dominated by filter-feeders, reflecting the potential effect that increased air exposure and heat stress has on different types of invertebrates. The lower intertidal zone also supported greater overall invertebrate counts compared to the upper intertidal zone (Figure 14).

Overall, despite being degraded it appears as though the reefs sampled in subtropical Queensland are supporting similar invertebrate functional groups to one another as well as the Gladstone location, however, it should be noted that sampling effort was slightly lower at this site ( $n = 9$  per zone compared to  $n = 12$  per zone at all subtropical sites). These patterns highlight the importance of including tidal plane when assessing fauna composition as a condition indicator for shellfish reefs, and provide insights into reef-associated invertebrate community assemblages which can be used to locate other tropical reefs that could act as suitable baselines. As a recommendation for both MarECAT assessments and the rapid assessment tool, it is important that sampling covers all areas of a reef (across tidal inundations and zones) to avoid inadvertently biasing results.

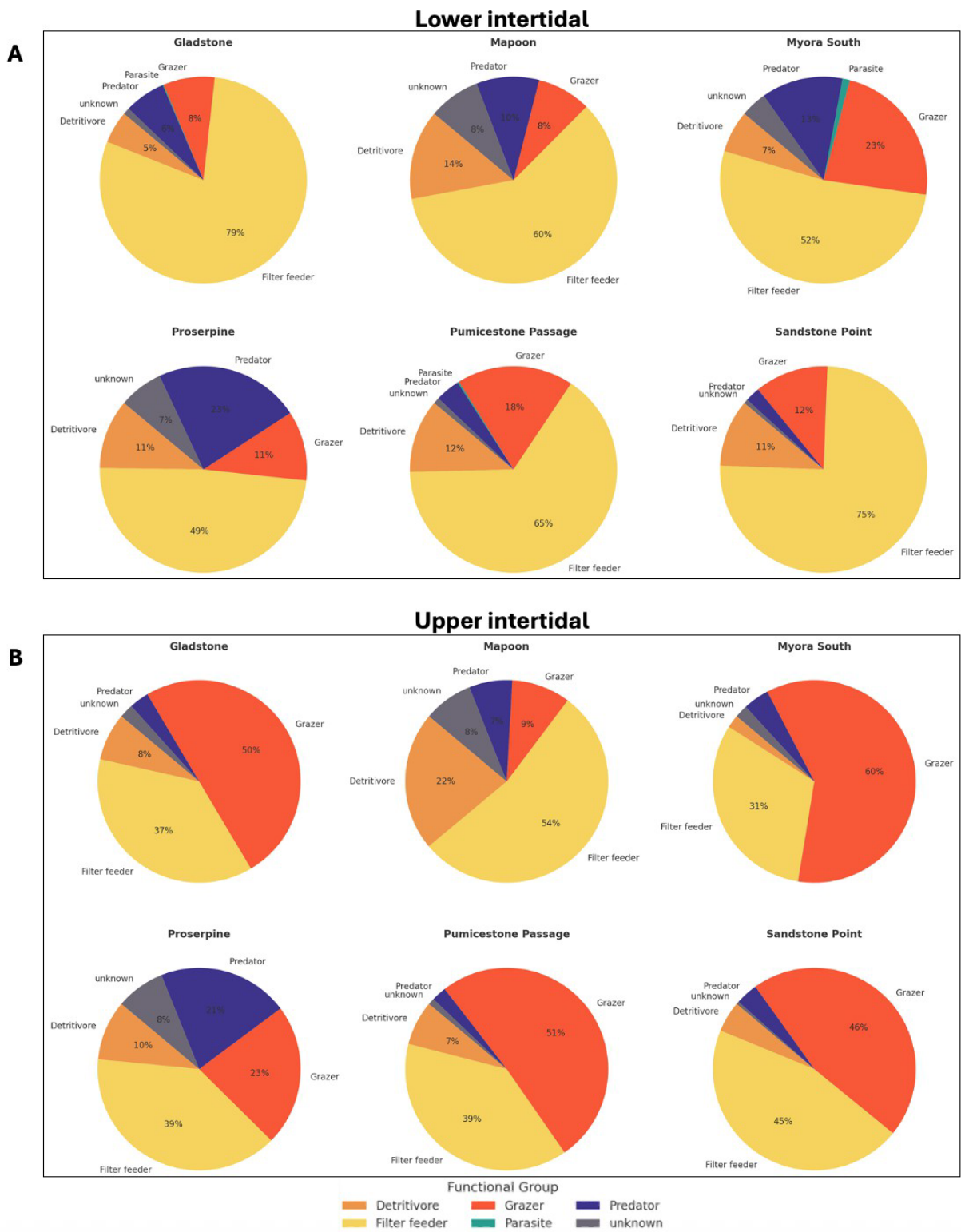


Figure 13. Proportional composition of functional groups within the lower intertidal zone (A) and the upper intertidal zone (B) across three surveyed locations in subtropical Queensland (Myora South, Pumicestone Passage and Sandstone Point) and three surveyed in tropical Queensland (Gladstone, Mapoon and Proserpine).

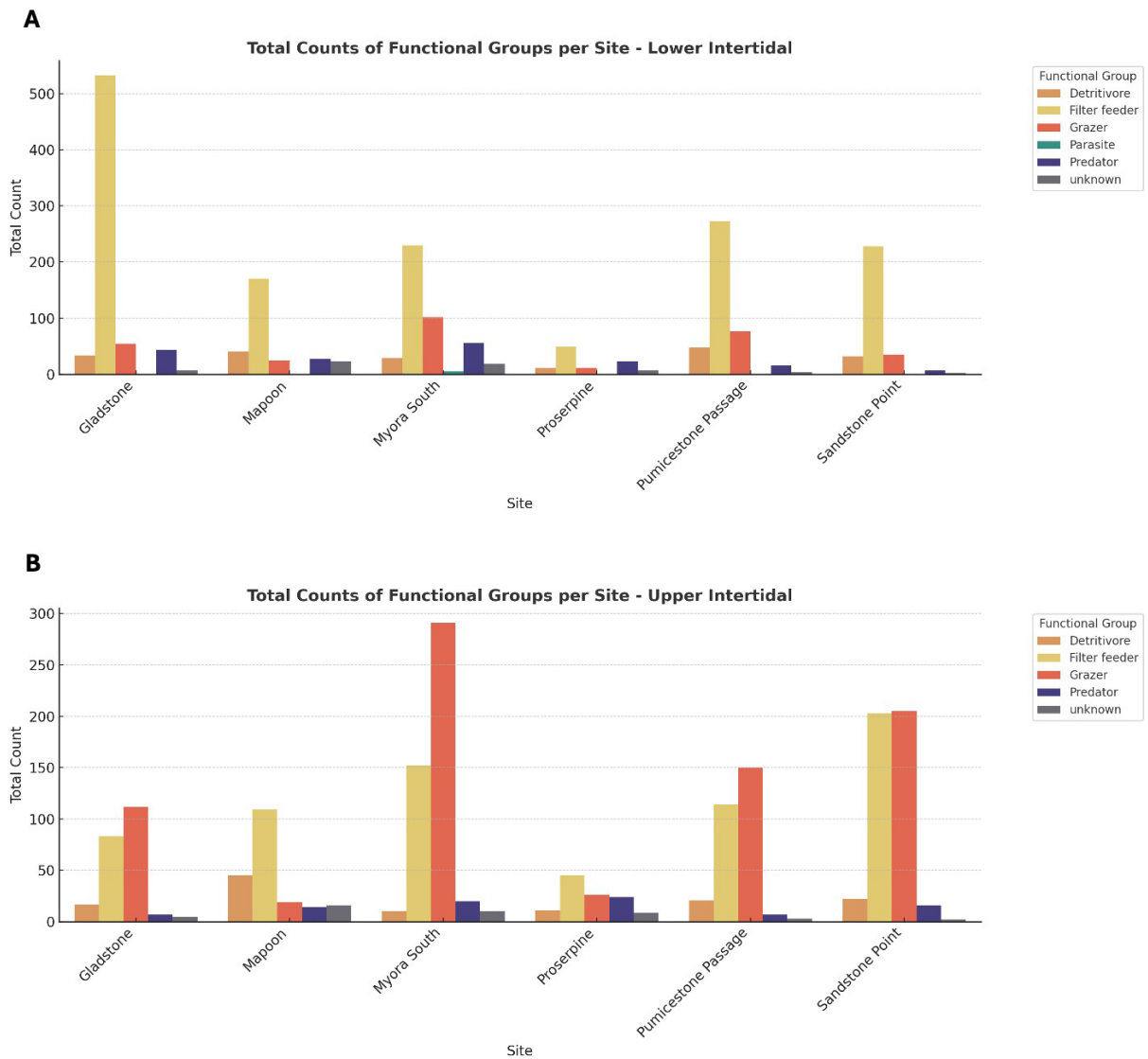


Figure 14. Total raw counts of functional groups per site in the lower intertidal zone (Panel A) and Upper intertidal zone (Panel B). Note that tropical sites (Gladstone, Mapoon and Proserpine) had a lower sampling effort of 9 replicates per intertidal zone where subtropical sites had 12 replicates per intertidal zone. Note the different y-axis between A and B.

# MarECAT

## Overview

The aim of this section is to provide information to enable future assessments of shellfish reefs using the Marine and Estuarine Condition Assessment Tool (MarECAT). The objective of a MarECAT assessment is to assess changes in benthic habitat conditions using a cross-ecosystem standardised indicator framework developed for Queensland (Cadier et al., 2024). There are a number of barriers that currently prevent MarECAT assessments from being conducted for shellfish reefs. The characterisations and mapping in this project represent the first comprehensive efforts to understand the present extent and condition of shellfish reefs in subtropical Queensland. Understanding a 'normal' condition for an ecosystem type from reference sites or reference information enables scoring condition indicators as follows:

**5** represents no disturbance to condition or ecosystem processes generally compared to what is understood to be normal for that wetland type.

**4** represents a low-level disturbance to condition, but the ecosystem is expected to maintain ongoing processes.

**3** represents a moderate-level disturbance to condition, with a likely change in ecosystem processes (evidence may not be clear).

**2** represents a high-level disturbance to condition with a clear change in ecosystem processes.

**1** represents a severe disturbance to condition, to the point where the ecosystem processes overall are barely functioning as it should.

**0** typically represents contribution to the collapse of the ecosystem for that indicator and possibly a change in ecosystem type.

Scores need to be evidence based which are then applied during the monitoring process. Although we have some understanding of the extent of historical shellfish reefs, there is little or no data that can be translated into metrics that describe the condition of these ecosystems. All present reefs in subtropical Queensland are now degraded, which means that we do not currently have evidence to reliably inform an accurate scoring system. Our current characterisations are therefore unable to assess changes to shellfish reefs using the MarECAT framework, nor inform a scoring system at this time.

To inform the establishment of a scoring system to enable future MarECAT assessments, we first undertook a typology exercise for the specific purpose of delineating different reef types. We then highlighted which condition indicators are most relevant to shellfish reefs, recommend metrics which should be collected to assess condition indicators, and outlines present knowledge gaps and how these can be addressed in future research. Once an evidence-based scoring system is established for different types of shellfish reefs, the characterisation data collected in this project can be appropriately scored for shellfish reefs in subtropical Queensland under the MarECAT framework.

## Typology

We used the same shellfish reef definitions stated in the Present reefs map section: “An area consisting of one or more reef patches with at least 5 m<sup>2</sup> total coverage by live shellfish, and dominated by at least 25% live shellfish cover. Reefs growing on hard substrate must be > 2 shellfish thick. Shellfish communities ≤ 2 shellfish thick (a veneer), < 5 m<sup>2</sup> total coverage by live shellfish, and/or less than 25% live shellfish cover are not considered reefs”.

The variety of different types of reef structures created by both the same and different species of shellfish means that different condition indicator thresholds will be required for different types of reefs. For example, rock oysters can naturally create a range of different types of structures, including high profile reefs (>15cm vertical height), low profile reefs (<15cm vertical height) and veneers on rocky substrates (at least 2 oysters thick) (NSW DPI, 2020). This means that there needs to be great care when establishing a scoring system to ensure that sites are not under or over scored based on thresholds that are not suitable to that site. For example, although the condition indicator “growth form” could be used for all of these reef types, the specific metric used for scoring would vary depending on the type of reef. To better understand condition indicator thresholds, we first conducted a typology of shellfish reefs to distinguish different reef types.

**Typology purpose:** To delineate the structural differences across native intertidal shellfish reef types in Queensland to facilitate appropriate condition indicator thresholds for future MarECAT assessments for different reef types.

**Attributes included:** Relative relief and structural macrobiota (Table 6). Note that invasive species have not been included in structural macrobiota they will not be used for restoration, nor do they fit within the purpose. To reduce types, mixed species reefs has also been excluded. Where mixed species reefs do occur, the allocated type should reflect the dominant reef-building species.

Table 6. Overview of shellfish reef typologies for future MarECAT assessments. Reef types are shown using cross-referenced attribute selections across structural macrobiota and relative relief\*.

THEME	BIOTA				TERRAIN				
Attribute	Structural macrobiota				Relative relief				
Category	Mollusc - rock oysters	Mollusc - leaf oysters	Mollusc - pearl oysters	Mollusc - mussels	Very low	Low	Medium	High	Very high
Collapsed	Mollusc - rock oysters	Mollusc - leaf oysters	Mollusc - pearl oysters	Mollusc - mussels	Veneer ( $\leq 2$ oysters thick)	Low ( $< 15$ cm)		High (15cm and greater)	
1. Rock oyster veneer	x				x				
2. Low profile rock oyster reef	x					x			
3. High profile rock oyster reef	x							x	
4. Low profile leaf oyster reef		x				x			
5. Low profile pearl oyster reef			x			x			
6. Low profile mussel reef				x		x			

\*Note that relative relief is measured as the relief of oysters on any substrate composition, whether terrigenous or biogenic/calcareous/shell.

**Rationale:** We suggest that the typology purpose in this instance should expand beyond subtropical Queensland because metrics for “normal” reefs may not exist in this region. In leu of appropriate baseline reefs in this region, we recommend incorporating metrics from additional reefs that will be characterised in tropical Queensland as these may be able to more reliably inform evidence-based scoring for MarECAT assessments (so long as they have shown to be functionally similar). By taking this approach, this will better align with future EPBC assessments while dealing with taxonomic ambiguities within the genus *Saccostrea*. This typology is currently restricted to intertidal shellfish reefs as subtidal shellfish reefs remain data deficient.

## Suggested condition indicators

To facilitate the development of a MarECAT assessment for shellfish reefs, we compiled condition indicators for all wetland types from (Cadier et al., 2024). We then assessed which indicators were relevant to intertidal shellfish reefs and provide a rationale for this decision.

Table 7. Available MarECAT categories for monitoring. Categories have been marked as suitable (yes), not relevant (no), or data deficient (DD). Note that “C5 Vegetation Composition” and “C6 Vegetation Stress” have not been included as they are not applicable to shellfish reefs.

Categories	Condition indicators	Suitability	Rationale
C1 Water regime	Tidal inundation	Yes	Hours/inundation will allow a MarECAT assessment across broad regions of shellfish reefs with different tidal regimes.
	Energy magnitude	Yes	Shellfish reefs in southern Queensland typically occur in sheltered areas. Water movement (tidal flow) is data deficient.
C2 Water quality	Temperature	Yes	Temperature varies greatly across seasons and tides in intertidal estuaries, and different shellfish species can tolerate a wide range. To use temperature as an indicator, long term datasets and consistent monitoring is required, as short-term measurements can be highly misleading.
	Salinity	Yes	Although salinity varies greatly across seasons and tides in intertidal estuaries, salinity could be linked to QX outbreaks.
	pH	Yes	pH varies greatly across seasons and tides in intertidal estuaries, and different shellfish species can tolerate a wide range. Meaningful interpretation of pH would require sustained monitoring over time, as short-term measurements can be highly misleading.
	Turbidity	Yes	Oyster reefs occur in a wide range of turbidity levels which fluctuate frequently with tidal movements and rain. As with temperature and pH, turbidity can only be meaningfully interpreted using long-term datasets and consistent monitoring. Great care needs to be taken as single observations may not reflect usual conditions.
	Dissolved oxygen (DO)	Yes	Hypoxia or anoxia conditions lead to major kills of marine and estuarine life.
	Nutrients	Yes	Excessive loads of nutrients can cause the eutrophication of coastal waterways. Could be linked to QX outbreaks.
	Acid sulphate runoff	DD	Data deficient
	Pollution	Yes	Could be linked to QX outbreaks or mortality events.
C3 Substrate dynamics	Substrate elevation	Yes	Changes to substrate elevation could result in areas that are no longer suitable for intertidal shellfish reefs.
	Substrate disturbance	DD	Data deficient
C4 Substrate characteristics	Temperature	Yes	Elevated surface temperatures could inhibit reef-development/ persistence.
	Salinity	Yes	Prolonged periods of low salinity can result in oyster mortality.

	Greenhouse gas emissions	DD	Data deficient
	Porosity	DD	Data deficient
	Grain size	Yes	The presence of shell in or on top of substrate is necessary for a shellfish reef. Excessive shell could indicate mass die offs.
	Substrate composition	Yes	Substrate composition can influence settlement, stability, and persistence of reefs. Changes can indicate suitability for reef development or signals of past mortality (excessive shell hash).
	Oxygen	DD	Data deficient
	Carbon and Nitrogen content	DD	Data deficient
	Acid sulphate soils	DD	Data deficient
	Pollution	DD	Data deficient
C7 Fauna composition	Abundance	Yes	Important indicator of a functioning shellfish reef.
	Diversity	Yes	A decrease in species diversity could alter the resilience of the habitat.
	Growth form	Yes	A decrease in shells volume may decrease recruitment potential. Reef height and percent cover are better metrics than live oyster density (which can be variable).
	Recruitment potential	Yes	Spat/shell should not be used as an indicator. Spat recruitment can be high after mass oyster mortality, giving a false high condition indicator score. Spat recruitment is highly variable across seasons. Suggest using evidence of multiple age/size classes instead.
	Functional groups	Yes	Macrobenthos invertebrates or fish functional groups as a relative percentage are an indication that diverse ecological services are being facilitated.
	Habitat use	Yes	An indication that other ecological processes (e.g., breeding) are being supported.
C8 Fauna threats	Fauna health	Yes	Mass mortality can be an indication of QX/disease outbreak.
	Non-preferred fauna	Yes	Invasive species ( <i>Magallana ariakensis</i> and <i>Magallana bilineata</i> ) have the potential to outcompete native species and introduce new pathogens.
C9 Litter	Debris	DD	Data deficient
	Illegal dumping	DD	Data deficient
C10 Extreme events	Fire regime	No	Not relevant to shellfish reefs
	Storms	Yes	Severe storms can bury shellfish reefs in sediment.
	Extreme emersion event	DD	Data deficient
	Marine heatwave	Yes	Excess heat can cause mass mortality events
	Pest outbreaks	DD	Data deficient – not counting QX disease as a pest

## Conservation Needs and Research Gaps

Shellfish reefs in subtropical Queensland are complicated to assess compared to other wetland habitats as they were largely lost before we even knew their extent and characteristics (Saville-Kent, 1891). This disappearance has left significant gaps in our ecological knowledge and created challenges for restoration and management. Although historical accounts of shellfish reefs have proven to be useful in identifying areas where shellfish reefs have been lost, quantifying losses is more difficult and current estimates are likely inaccurate. For example, a 90% estimate (Gillies et al., 2020) is based on the presence/ absence of reefs in locations due to a lack of quantified historical spatial data, while 96% estimates by Diggles, 2013 is in relation to vertical zonation suitable for oyster growth, not reef area. Furthermore, these estimates were made with the assumption that *Saccostrea glomerata* occurs both intertidally and subtidally, which emerging evidence is suggesting may not be the case. The condition of these historical reefs also remain largely unknown. Fundamentally, we still lack a clear picture of what a “healthy” shellfish reef looks like in subtropical Queensland, making it difficult to establish appropriate thresholds for indicators of condition, such as those used in the MarECAT framework. To address this, we suggest using other “normal” or “high-quality” reefs in tropical Queensland or New South Wales to develop an evidence-based scoring system for condition indicators for future monitoring.

One of the most pressing uncertainties is the ongoing issue of taxonomic ambiguities and accurate species identifications. Although *Saccostrea glomerata* and *Saccostrea* lineage B reefs could be monitored in the same ways, the biology of Lineage B (including settlement preferences and spawning triggers) remains unknown but are likely different to those of *S. glomerata* (Richardson et al., 2022). Future restoration in subtropical Queensland will need to consider these potential differences, understand the true distribution of each reef-building species, and how they interact in transitional areas. This will require future oyster sampling work using molecular tools for accurate species identification (McDougall et al., 2024), which is now much more feasible and cost-effective with the development of species-specific primers (McDougall and Walker, 2021; Richardson et al., 2024). Understanding the distribution of reef-building species should be incorporated in habitat suitability assessments. Doing so will not only aid in identifying where species are currently able to persist but also highlight suitable habitats that fall outside their present distribution. These areas could represent priority sites for restoration or conservation, particularly where species have been lost locally but environmental conditions remain favourable for re-establishment. Furthermore, there is a growing body of evidence supporting the notion that *S. glomerata* is an intertidal specialist. If this is the case, this species may be less threatened than originally thought, however, it means that the species responsible for building reefs subtidally would likely be even more threatened, or possibly extinct. In this report, we suggest that subtidal reef-building species were likely *Magallana dactylena* as well as unidentified species

which do not appear to belong to the genus *Saccostrea*. For the restoration of subtidal shellfish reefs, an essential first step is to learn which species are reef-building which will require targeted searches and molecular work.

Although not a focus of this project, one of the most significant challenges faced by *S. glomerata* is the threat of QX disease, caused by the protozoan parasite *Marteilia sydneyi*, which can cause mortality rates of up to 98% (Raftos et al., 2014). The parasites life cycle, transmission mechanisms, and intermediate hosts are not well understood, making it difficult to predict outbreaks or manage disease risk. The absence of early detection tools places both commercial aquaculture and ecological restoration efforts at risk. Furthermore, it is unclear whether other species of *Saccostrea* are also susceptible to QX disease.

In our assessments, we found that there has likely been a shift from soft-sediment reefs to rock-based reefs in subtropical Queensland, indicating that the former reef type may be in greater need of protection and restoration. Future characterisations in other regions such as tropical Queensland may offer a better insight into the proportion of naturally occurring soft sediment vs rock-based reefs to inform future restoration targets.

In summary, the key conservation needs are:

- Accurate identification of reef-building species (using molecular tools) and mapping their distributions both intertidally and sub-tidally.
- Characterisation of “normal” or high-quality reefs in regions outside subtropical Qld to act as proxies for developing evidence-based scoring systems withing MarECAT. Prior
- Prioritisation of reef restoration, with a primary focus on intertidal habitats until subtidal reef-building species are better understood.
- Assessment of whether soft-sediment reefs are in greater need of restoration and protection than rock-based reefs.
- Protection and management of existing reef sites to maintain current biodiversity and ecosystem services.

Ultimately, the success of shellfish reef restoration in subtropical Queensland depends on filling critical knowledge gaps and adopting an adaptive, evidence-based approach to conservation. In the absence of perfect historical data, we must build a robust and flexible framework for assessment and restoration that is guided by both region-specific research and species-specific biology as well as broader ecological insights.

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## Appendix A: Site photographs for all mapped shellfish habitats and map insets

\*Refer to author for request of photos.

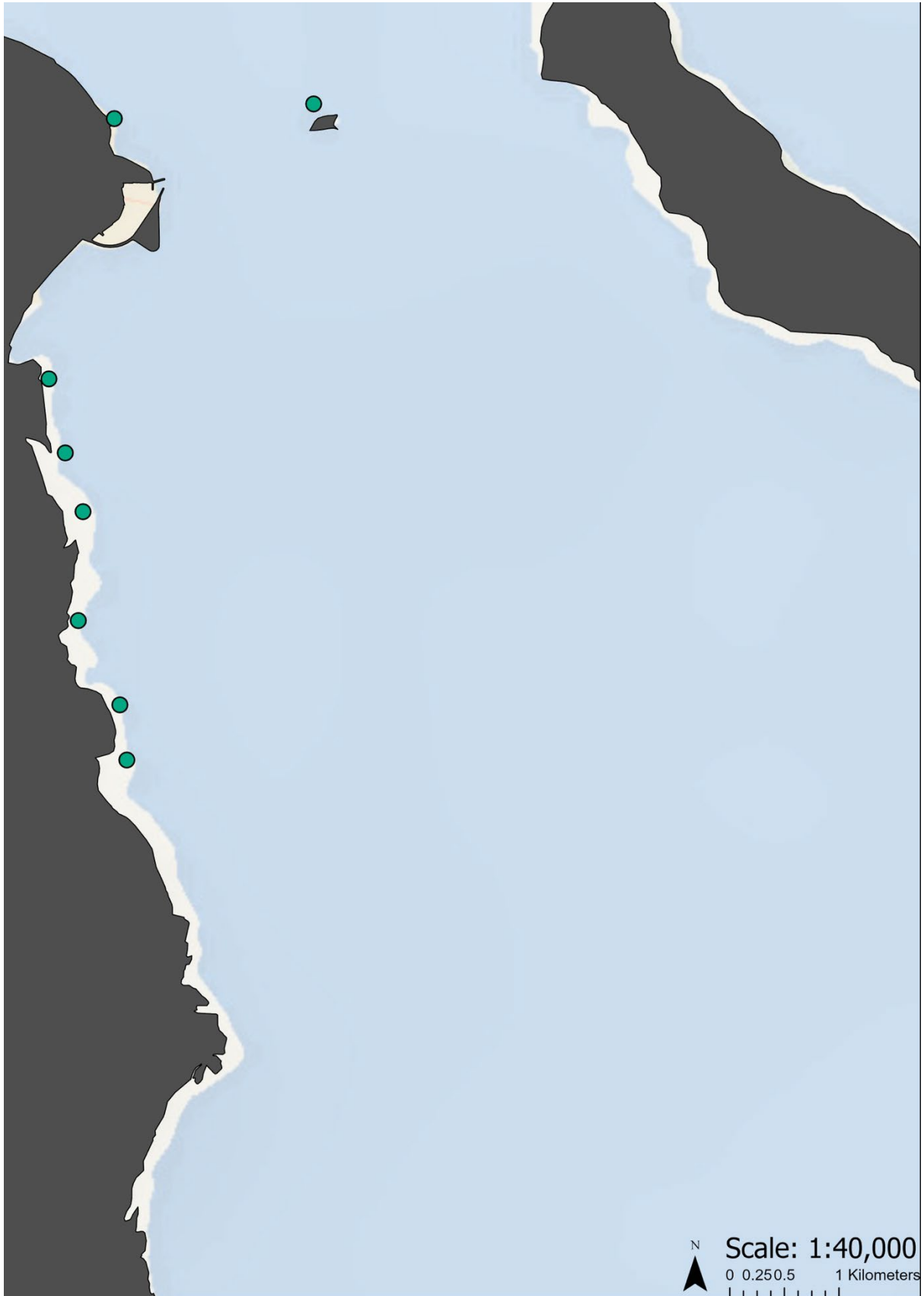
# Historical Inset 1



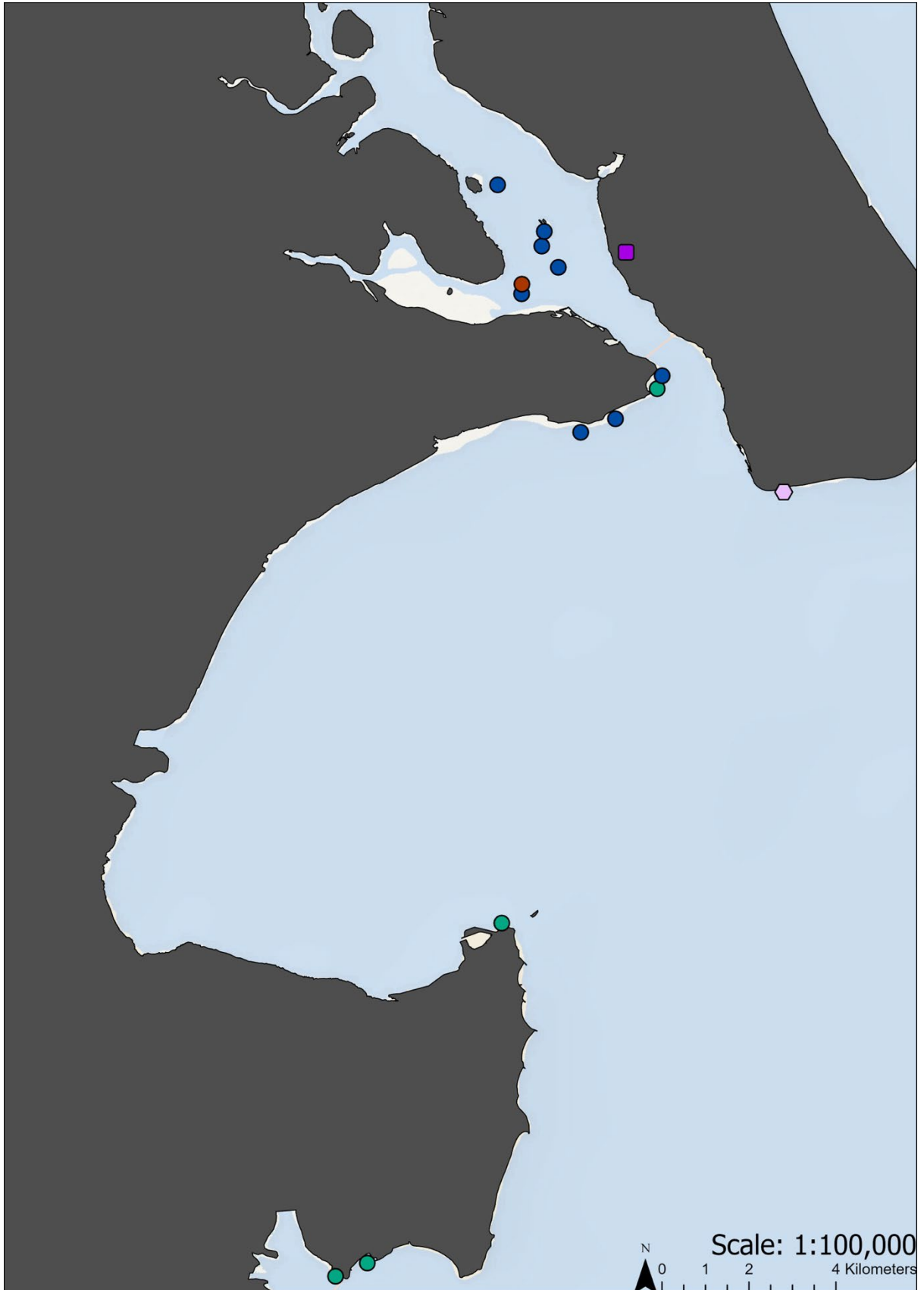
Historical Inset 2



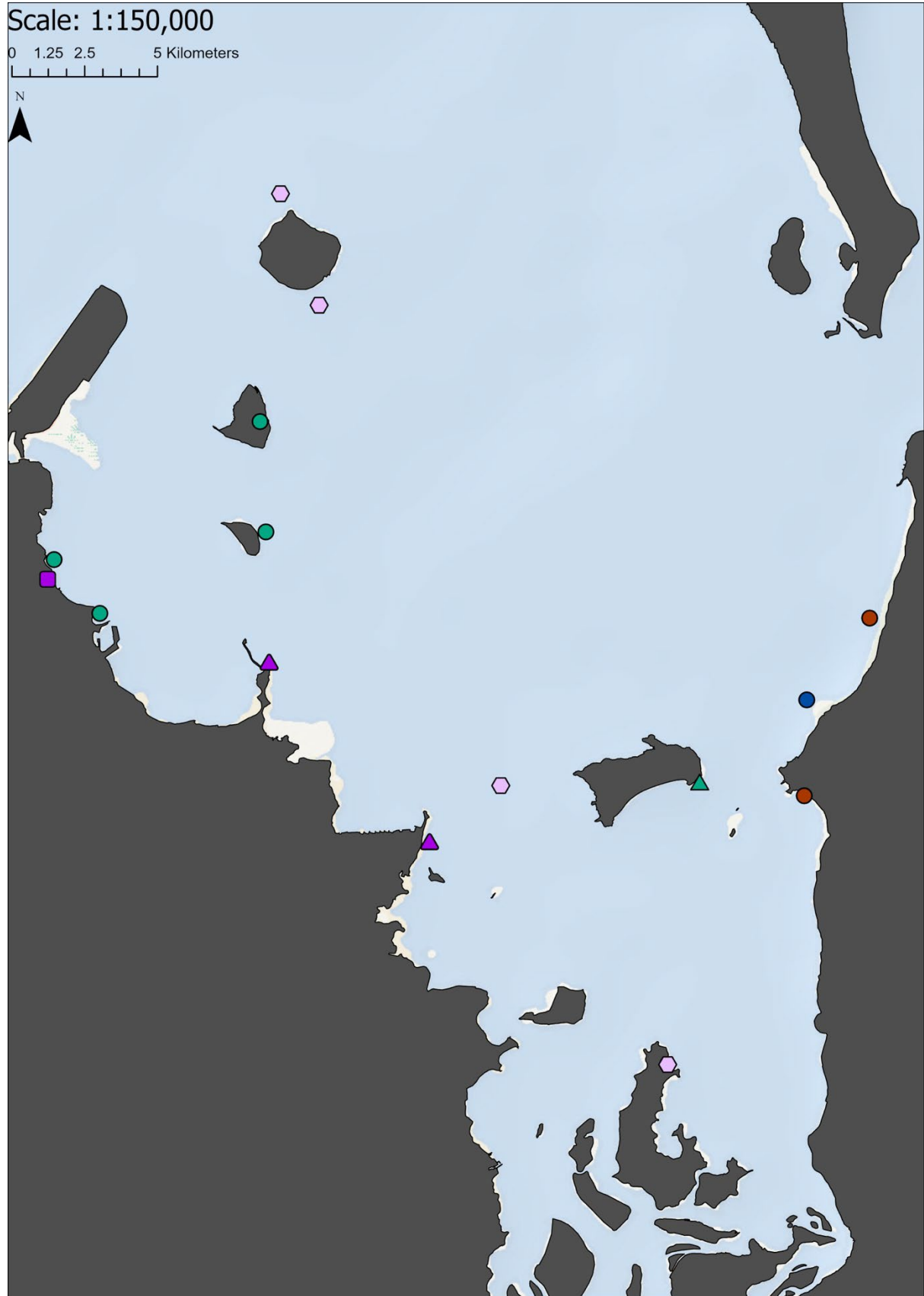
Present Inset 1



Present Inset 2



Present Inset 3



## Appendix B: Data to inform historical and present reef locations

Table S1: Data to inform historical shellfish reefs.

<b>Coordinates Y</b>	<b>Coordinates X</b>	<b>LOCATION</b>	<b>TIDAL ZONE</b>	<b>COMMON NAME</b>	<b>SOURCE</b>
-27.47948131	153.4030599	Stradbroke shore	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.3913268	153.4390644	Amity Point	Unknown	Pearl oysters	<a href="https://trove.nla.gov.au/newspaper/article/235774009?searchTerm=Pearl%20shell%20shell%20pinctada%20oyster%20pearl%20pearling">https://trove.nla.gov.au/newspaper/article/235774009?searchTerm=Pearl%20shell%20shell%20pinctada%20oyster%20pearl%20pearling</a>
-27.3913268	153.4390644	Amity Point	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.36582421	153.3843615	Boolong bank	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-26.98558211	153.1641095	Bribie Passage	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.88367445	153.3798693	Coombabah creek	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.83416419	153.3913683	Coomera creek	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.89474272	153.3655979	Coomera, Coombabah	Subtidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.34638694	153.3732128	Coonungai bank	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.90557178	153.418611	Curragee passage	Subtidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.90557178	153.418611	Curragee passage	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.18546974	153.0324612	Deception Bay	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.49552247	153.3949454	Dunwich	Unknown	Pearl oysters	<a href="https://trove.nla.gov.au/newspaper/article/37061217?searchTerm=oyster%20Quampies">https://trove.nla.gov.au/newspaper/article/37061217?searchTerm=oyster%20Quampies</a>
-29.12220123	153.4307486	Evan River	Unknown	Pearl oysters	<a href="https://trove.nla.gov.au/newspaper/article/235155523?searchTerm=Pearl%20oyster%20shell%20pinctada%20oyster%20weerlie%20Margaritifera">https://trove.nla.gov.au/newspaper/article/235155523?searchTerm=Pearl%20oyster%20shell%20pinctada%20oyster%20weerlie%20Margaritifera</a>
-25.25336223	152.7833527	Hervey Bay	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials

-27.17800031	153.3502052	Moreton Island	Subtidal	Pearl oysters	<a href="https://trove.nla.gov.au/newspaper/article/12930133?searchTerm=Pearl%20shell%20shell%20pinctada%20weerlie%20Margaritifera">https://trove.nla.gov.au/newspaper/article/12930133?searchTerm=Pearl%20shell%20shell%20pinctada%20weerlie%20Margaritifera</a>
-27.46569015	153.4144866	Myora	Intertidal	Leaf oysters	Multiple specimens from museum
-26.36733289	153.0211044	Noosa River	Unknown	Pearl oysters	<a href="https://trove.nla.gov.au/newspaper/article/70968421?searchTerm=Pearl%20oyster%20shell%20pinctada%20Ooyster%20weerlie%20Margaritifera">https://trove.nla.gov.au/newspaper/article/70968421?searchTerm=Pearl%20oyster%20shell%20pinctada%20Ooyster%20weerlie%20Margaritifera</a>
-27.48767477	153.3725096	Peel Island	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.81895059	153.3909187	Pimpama creek	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.8208108	153.38518	Pimpama creek	Subtidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.0272859	153.1147839	Pumicestone Passage	Subtidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.42066956	153.4185625	Rainbow channel	Subtidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.22647039	153.1191922	Redcliffe	Unknown	Pearl oysters	Multiple specimens from museum
-27.40040729	153.4248653	Rous channel	Subtidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-27.96037664	153.4179934	Southport	Intertidal	Leaf oysters	Multiple specimens from museum
-27.96037664	153.4179934	Southport	Unknown	Pearl oysters	Multiple specimens from museum
-27.44315692	153.4218165	Stradbroke Island west	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-28.11005141	153.4459054	Tallebudgera Creek	Intertidal	Rock oysters	Thurstan et al., (2020) supplementary materials
-26.37282735	153.0110324	Tewantin	Unknown	Rock oysters	Thurstan et al., (2020) supplementary materials
-25.86434937	153.0234972	Tin Can Bay	Intertidal	Leaf oysters	Multiple specimens from museum
-25.86434937	153.0234972	Tin Can Bay	Unknown	Pearl oysters	Multiple specimens from museum
-27.7558565	153.4290096	Tipplers passage	Subtidal	Rock oysters	Thurstan et al., (2020) supplementary materials

Table S2: Present reef locations and habitat descriptions.

Location	X, Y	Zone	Habitat type	Habitat description	Species	Mapping products
Elliott Heads	-24.929844 152.474375	Intertidal	Reef patches	Small reef patches	<i>Saccostrea glomerata</i> or Lineage B	Present map + Polygon
Elliott River	-24.931007 152.472207	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i> or Lineage B	Present map
Walkers Point	-25.171561 152.588312	Intertidal	Reef patches	Small reef patches	<i>Saccostrea glomerata</i> or Lineage B	Present map + Polygon
Hervey Bay	-25.287644 152.908757	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i> or Lineage B	Present map
Round Island	-25.286431 152.925172	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i> or Lineage B	Present map
Booral	-25.309055 152.903373	Intertidal	Encrusting oysters	High density	<i>Saccostrea glomerata</i> or Lineage B	Present map + Polygon
Booral 2	-25.315166 152.904724	Intertidal	Encrusting oysters	High density	<i>Saccostrea glomerata</i> or Lineage B	Present map + Polygon
Island View	-25.319983 152.906172	Intertidal	Encrusting oysters	High density	<i>Saccostrea glomerata</i> or Lineage B	Present map + Polygon
Ti Tree Road E	-25.328953 152.905804	Intertidal	Encrusting oysters	High density	<i>Saccostrea glomerata</i> or Lineage B	Present map + Polygon
Janine Road	-25.335889 152.909223	Intertidal	Encrusting oysters	High density	<i>Saccostrea glomerata</i> or Lineage B	Present map + Polygon
Sea Eagles Road	-25.34043 152.909791	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i> or Lineage B	Present map
Maaroom	-25.613354 152.875111	Intertidal	Established	Oyster reef	<i>Isognomon ehippium</i>	Present map + Polygon
Boonooroo	-25.66983 152.905882	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i> or Lineage B	Present map
Poona	-25.710292 152.9234	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i> or Lineage B	Present map
Weyba Creek	-26.403642 153.081194	Subtidal	Isolated population	Low density	<i>Isognomon ehippium</i>	Present map
Noosa River estuary	-26.396727 153.063876	Subtidal	Isolated population	Low density	<i>Pinctada</i> sp.	Present map

Banksia Beach	-27.051433 153.137879	Intertidal	Isolated population	Low density	<i>Isognomon ehippium</i>	Present map
Red Beach	-27.10101 153.170442	Subtidal	Isolated population	Low density	<i>Magallana dactylena</i>	Present map
Pumicestone Passage 2	-27.050141 153.120466	Intertidal	Established	Oyster reef	<i>Saccostrea glomerata</i>	Present map + Polygon
Pumicestone Passage 3	-27.047135 153.120981	Intertidal	Established	Oyster reef	<i>Saccostrea glomerata</i>	Present map + Polygon
Pumicestone Passage 1	-27.054555 153.123865	Intertidal	Established	Oyster reef	<i>Saccostrea glomerata</i>	Present map + Polygon
Pumicestone Passage 4	-27.037491 153.111316	Intertidal	Established	Oyster reef	<i>Saccostrea glomerata</i>	Present map + Polygon
Pumicestone Passage 5	-27.058015 153.116349	Intertidal	Reef patches	Small reef patches	<i>Saccostrea glomerata</i>	Present map + Polygon
Pumicestone Passage 6	-27.060011 153.116315	Intertidal	Established	Oyster reef	<i>Saccostrea glomerata</i>	Present map + Polygon
Toorbul Point 1	-27.076958 153.145314	Intertidal	Encrusting oysters	High density	<i>Saccostrea glomerata</i>	Present map + Polygon
Toorbul Point 2	-27.079669 153.144323	Intertidal	Encrusting oysters	High density	<i>Saccostrea glomerata</i>	Present map + Polygon
Sandstone Point 1	-27.085889 153.135669	Intertidal	Established	Oyster reef	<i>Saccostrea glomerata</i>	Present map + Polygon
Sandstone Point 2	-27.088644 153.128476	Intertidal	Established	Oyster reef	<i>Saccostrea glomerata</i>	Present map + Polygon
Scarborough	-27.190158 153.112153	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i>	Present map
Redcliffe	-27.260388 153.0844	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i>	Present map
Clontarf	-27.263177 153.077849	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i>	Present map
Moreton Island Wrecks	-27.162855 153.3683	Intertidal	Encrusting oysters*	High density	<i>Saccostrea glomerata</i> , <i>Saccostrea scyphophilla</i>	Present map
Mud Island	-27.318733 153.24466	Subtidal	Isolated population	Low density	Clam?	Present map

Mud Island	-27.353137 153.256584	Subtidal	Isolated population	Low density	non- <i>Saccostrea</i> : <i>Hyotissa</i> and unknown?	Present map
St Helena Island	-27.389031 153.238344	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i>	Present map
Green Island	-27.423156 153.240117	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i>	Present map
Wynnum 1	-27.4483 153.1889	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i>	Present map
Wynnum 2	-27.4317 153.1748	Intertidal	Encrusting oysters	Low density	<i>Saccostrea glomerata</i>	Present map
Wynnum Creek	-27.437752 153.172798	Intertidal	Isolated population	Low density	<i>Isognomon ehippium</i>	Present map
Wellington Point	-27.463334 153.241153	Intertidal	Remnant population	Low density	<i>Saccostrea glomerata</i> + <i>Trichomya hirsuta</i>	Present map
Cleveland	-27.518753 153.290682	Intertidal	Remnant population	Low density	<i>Isognomon ehippium</i> + <i>Trichomya hirsuta</i>	Present map
Myora north	-27.44973 153.426536	Intertidal	Remnant reef patches	Oyster reef	<i>Saccostrea glomerata</i>	Present map + Polygon
Myora south	-27.474984 153.407117	Intertidal	Established	Oyster reef	<i>Saccostrea glomerata</i>	Present map + Polygon
Dunwich	-27.504548 153.406332	Intertidal	Remnant reef patches	Oyster reef	<i>Saccostrea glomerata</i>	Present map + Polygon
Peel Island	-27.501428 153.312646	Subtidal	Remnant population	Low density	<i>Trichomya hirsuta</i> + Clam?	Present map
SS Platypus Bay	-27.500348 153.374048	Intertidal	Encrusting oysters*	High density	<i>Saccostrea glomerata</i> + <i>Saccostrea scyphophilla</i> + <i>Trichomya hirsuta</i>	Present map
Macleay Island	-27.587559 153.36417	Subtidal	Remnant population	Low density	Clam?	Present map
Tallebudgera Creek	-28.099039 153.456699	Intertidal	Encrusting oysters	High density	<i>Saccostrea glomerata</i>	Present map + Polygon

\*Indicates no polygon due to the artificial nature of the substrate (shipwreck).

